



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : <b>C12P 21/00, A61K 37/36 C07K 13/00</b>	<b>A1</b>	(11) International Publication Number: <b>WO 90/11366</b> (43) International Publication Date: <b>4 October 1990 (04.10.90)</b>
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(21) International Application Number: **PCT/US90/01630**(22) International Filing Date: **27 March 1990 (27.03.90)**

## (30) Priority data:

329,610	28 March 1989 (28.03.89)	US
347,559	4 May 1989 (04.05.89)	US
370,544	23 June 1989 (23.06.89)	US
370,547	23 June 1989 (23.06.89)	US
370,549	23 June 1989 (23.06.89)	US
437,409	15 November 1989 (15.11.89)	US
438,919	17 November 1989 (17.11.89)	US
440,033	7 March 1990 (07.03.90)	US

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+ pean patent), CA, CH (European patent), DE (Euro-  
pean patent), DK (European patent), ES (European pa-  
tent), FR (European patent), GB (European patent), IT  
(European patent), JP, KR, LU (European patent), NL  
(European patent), SE (European patent).****Published***With international search report.*(54) Title: **OSTEOINDUCTIVE COMPOSITIONS**

## (57) Abstract

Purified BMP-5, BMP-6 and BMP-7 proteins and processes for producing them are disclosed. The proteins may be used in the treatment of bone and/or cartilage defects and in wound healing and related tissue repair.

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## OSTEOINDUCTIVE COMPOSITIONS

The present invention relates to proteins having utility in the formation of bone and/or cartilage. In particular the invention relates to a number of families of purified proteins, termed BMP-5, BMP-6 and BMP-7 protein families (wherein BMP is Bone Morphogenic Protein) and processes for obtaining them. These proteins may exhibit the ability to induce cartilage and/or bone formation. They may be used to induce bone and/or cartilage formation and in wound healing and tissue repair.

The invention provides a family of BMP-5 proteins. Purified human BMP-5 proteins are substantially free from other proteins with which they are co-produced, and characterized by an amino acid sequence comprising from amino acid #323 to amino acid #454 set forth in Table III. This amino acid sequence #323 to #454 is encoded by the DNA sequence comprising nucleotide #1665 to nucleotide #2060 of Table III. BMP-5 proteins may be further characterized by an apparent molecular weight of 28,000-30,000 daltons as determined by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE). Under reducing conditions in SDS-PAGE the protein electrophoreses with a molecular weight of approximately 14,000 - 20,000 daltons. It is contemplated that these proteins are capable of stimulating, promoting, or otherwise inducing cartilage and/or bone formation.

The invention further provides bovine BMP-5 proteins comprising amino acid #9 to amino acid #140 set forth in Table I. The amino acid sequence

from #9 to #140 is encoded by the DNA sequence comprising nucleotide #32 to #427 of Table I. These proteins may be further characterized by an apparent molecular weight of 28,000 - 30,000 daltons as determined by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE). Under reducing conditions in SDS-PAGE the protein electrophoreses with a molecular weight of approximately 14,000-20,000 daltons. It is contemplated that these proteins are capable of inducing cartilage and/or bone formation.

Human BMP-5 proteins of the invention may be produced by culturing a cell transformed with a DNA sequence containing the nucleotide sequence the same or substantially the same as the nucleotide sequence shown in Table III comprising nucleotide #699 to nucleotide #2060. BMP-5 proteins comprising the amino acid sequence the same or substantially the same as shown in Table III from amino acid # 323 to amino acid # 454 are recovered, isolated and purified from the culture medium.

Bovine BMP-5 proteins may be produced by culturing a cell transformed with a DNA sequence containing the nucleotide sequence the same or substantially the same as that shown in Table I comprising nucleotide #8 through nucleotide #427 and recovering and purifying from the culture medium a protein containing the amino acid sequence or a portion thereof as shown in Table I comprising amino acid #9 to amino acid #140.

The invention provides a family of BMP-6 proteins. Purified human BMP-6 proteins, substantially free from other proteins with which they are co-produced and are characterized by an amino acid sequence comprising acid #382 to amino



acid #513 set forth in Table IV. The amino acid sequence from amino acid #382 to #513 is encoded by the DNA sequence of Table IV from nucleotide #1303 to nucleotide #1698. These proteins may be further characterized by an apparent molecular weight of 28,000-30,000 daltons as determined by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE). Under reducing conditions in SDS-PAGE the protein electrophoreses with a molecular weight of approximately 14,000 - 20,000 daltons. It is contemplated that these proteins are capable of stimulating promoting, or otherwise inducing cartilage and/or bone formation.

The invention further provides bovine BMP-6 proteins characterized by the amino acid sequence comprising amino acid #121 to amino acid #222 set forth in Table II. The amino acid sequence from #121 to #222 is encoded by the DNA sequence of Table II from nucleotide #361 to #666 of Table II. These proteins may be further characterized by an apparent molecular weight of 28,000 - 30,000 daltons as determined by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE). Under reducing conditions in SDS-PAGE the protein electrophoreses with a molecular weight of approximately 14,000-20,000 daltons. It is contemplated that these proteins are capable of inducing cartilage and/or bone formation.

Human BMP-6 proteins of the invention are produced by culturing a cell transformed with a DNA sequence comprising nucleotide #160 to nucleotide #1698 as shown in Table III or a substantially similar sequence. BMP-6 proteins comprising amino acid #382 to amino acid #513 or a substantially similar sequence are recovered, isolated and

purified from the culture medium.

Bovine BMP-6 proteins may be produced by culturing a cell transformed with a DNA comprising nucleotide #361 through nucleotide #666 as set forth in Table II or a substantially similar sequence and recovering and purifying from the culture medium a protein comprising amino acid #121 to amino acid #222 as set forth in Table II.

The invention provides a family of BMP-7 proteins. Which includes purified human BMP-7 proteins, substantially free from other proteins with which they are co-produced. Human BMP-7 proteins are characterized by an amino acid sequence comprising amino acid #300 to amino acid #431 set forth in Table V. This amino acid sequence #300 to #431 is encoded by the DNA sequence of Table V from nucleotide #994 to #1389. BMP-7 proteins may be further characterized by an apparent molecular weight of 28,000-30,000 daltons as determined by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE). Under reducing conditions in SDS-PAGE the protein electrophoreses with a molecular weight of approximately 14,000 - 20,000 daltons. It is contemplated that these proteins are capable of stimulating, promoting, or otherwise inducing cartilage and/or bone formation.

Human BMP-7 proteins of the invention may be produced by culturing a cell transformed with a DNA sequence containing the nucleotide sequence the same or substantially the same as the nucleotide sequence shown in Table V comprising nucleotide #97 to nucleotide #1389. BMP-7 proteins comprising the amino acid sequence the same or substantially the same as shown in Table V from amino acid #300

to amino acid #431 are recovered, isolated and purified from the culture medium.

The invention further provides a method wherein the proteins described above are utilized for obtaining related human protein/s or other mammalian cartilage and/or bone formation protein/s. Such methods are known to those skilled in the art of genetic engineering. One method for obtaining such proteins involves utilizing the human BMP-5, BMP-6 and BMP-7 coding sequences or portions thereof to design probes for screening human genomic and/or cDNA libraries to isolate human genomic and/or cDNA sequences. Additional methods within the art may employ the bovine and human BMP proteins of the invention to obtain other mammalian BMP cartilage and/or bone formation proteins.

Having identified the nucleotide sequences, the proteins are produced by culturing a cell transformed with the nucleotide sequence. This sequence or portions thereof hybridizes under stringent conditions to the nucleotide sequence of either BMP-5, BMP-6 or BMP-7 proteins and encodes a protein exhibiting cartilage and/or bone formation activity. The expressed protein is recovered and purified from the culture medium. The purified BMP proteins are substantially free from other proteinaceous materials with which they are co-produced, as well as from other contaminants.

BMP-5, BMP-6 and BMP-7 proteins may be characterized by the ability to promote, stimulate or otherwise induce the formation of cartilage and/or bone formation. It is further contemplated that the ability of these proteins to induce the

formation of cartilage and/or bone may be exhibited by the ability to demonstrate cartilage and/or bone formation activity in the rat bone formation assay described below. It is further contemplated that the proteins of the invention demonstrate activity in this rat bone formation assay at a concentration of 10 $\mu$ g - 500 $\mu$ g/gram of bone formed. More particularly, it is contemplated these proteins may be characterized by the ability of 1 $\mu$ g of the protein to score at least +2 in the rat bone formation assay described below using either the original or modified scoring method.

Another aspect of the invention provides pharmaceutical compositions containing a therapeutically effective amount of a BMP-5, BMP-6 or BMP-7 protein in a pharmaceutically acceptable vehicle or carrier. Further compositions comprise at least one BMP-5, BMP-6 or BMP-7 protein. It is therefore contemplated that the compositions may contain more than one of the BMP proteins of the present invention as BMP-5, BMP-6 and BMP-7 proteins may act in concert with or perhaps synergistically with one another. The compositions of the invention are used to induce bone and/or cartilage formation. These compositions may also be used for wound healing and tissue repair.

Further compositions of the invention may include in addition to a BMP-5, BMP-6 or BMP-7 protein of the present invention at least one other therapeutically useful agent such as the proteins designated BMP-1, BMP-2 (also having been designated in the past as BMP-2A, BMP-2 Class I), BMP-3 and BMP-4 (also having been designated in the past as BMP-2B and BMP-2 Class II) disclosed in co-owned International Publication WO88/00205

published 14 January 1988 and International Publication WO89/10409 published 2 November 1989. Other therapeutically useful agents include growth factors such as epidermal growth factor (EGF),  
5 fibroblast growth factor (FGF), transforming growth factors (TGF- $\alpha$  and TGF- $\beta$ ), and platelet derived growth factor (PDGF).

The compositions of the invention may also include an appropriate matrix, for instance, for  
10 delivery and/or support of the composition and/or providing a surface for bone and/or cartilage formation. The matrix may provide slow release of the BMP protein and/or the appropriate environment for presentation of the BMP protein of the  
15 invention.

The compositions of the invention may be employed in methods for treating a number of bone and/or cartilage defects, and periodontal disease. They may also be employed in methods for treating  
20 various types of wounds and in tissue repair. These methods, according to the invention, entail administering a composition of the invention to a patient needing such bone and/or cartilage formation, wound healing or tissue repair. The  
25 method therefore involves administration of a therapeutically effective amount of a protein of the invention. These methods may also entail the administration of a protein of the invention in conjunction with at least one of the "BMP" proteins  
30 disclosed in the co-owned applications described above. In addition, these methods may also include the administration of a protein of the invention with other growth factors including EGF, FGF, TGF- $\alpha$ , TGF- $\beta$ , and PDGF.

35 Still a further aspect of the invention are

DNA sequences coding for expression of a protein of the invention. Such sequences include the sequence of nucleotides in a 5' to 3' direction illustrated in Tables I - V or DNA sequences which hybridize under stringent conditions with the DNA sequences of Tables I - V and encode a protein demonstrating ability to induce cartilage and/or bone formation. Such cartilage and/or bone formation may be demonstrated in the rat bone formation assay described below. It is contemplated that these proteins may demonstrate activity in this assay at a concentration of 10  $\mu$ g - 500  $\mu$ g/gram of bone formed. More particularly, it is contemplated that these proteins demonstrate the ability of 1 $\mu$ g of the protein to score at least +2 in the rat bone formation assay. Finally, allelic or other variations of the sequences of Tables I - V whether such nucleotide changes result in changes in the peptide sequence or not, are also included in the present invention.

A further aspect of the invention provides vectors containing a DNA sequence as described above in operative association with an expression control sequence therefor. These vectors may be employed in a novel process for producing a protein of the invention in which a cell line transformed with a DNA sequence directing expression of a protein of the invention in operative association with an expression control sequence therefor, is cultured in a suitable culture medium and a protein of the invention is recovered and purified therefrom. This claimed process may employ a number of known cells, both prokaryotic and eukaryotic, as host cells for expression of the polypeptide. The recovered BMP proteins are

purified by isolating them from other proteinaceous materials with which they are co-produced as well as from other contaminants.

Other aspects and advantages of the present invention will be apparent upon consideration of the following detailed description and preferred embodiments thereof.

#### Detailed Description of the Invention

Purified human BMP-5 proteins may be produced by culturing a host cell transformed with the DNA sequence of Table III. The expressed BMP-5 proteins are isolated and purified from the culture medium. Purified human BMP-5 proteins are expected to be characterized an amino acid sequence comprising amino acid #323 to #454 as shown in Table III. Purified BMP-5 human cartilage/bone proteins of the present invention are therefore produced by culturing a host cell transformed with a DNA sequence comprising nucleotide #699 to nucleotide #2060 as shown in Table III or substantially homologous sequences operatively linked to a heterologous regulatory control sequence and recovering and purifying from the culture medium a protein comprising the amino acid sequence as shown in Table III from amino acid #323 to amino acid #454 or a substantially homologous sequence.

In further embodiments the DNA sequence comprises the nucleotides encoding amino acids #323-#454. BMP-5 proteins may therefore be produced by culturing a host cell transformed with a DNA sequence comprising nucleotide #1665 to nucleotide #2060 as shown in Table III or substantially homologous sequences operatively linked to a

heterologous regulatory control sequence and recovering and purifying from the culture medium a protein comprising amino acid #323 to amino acid #454 as shown in Table III or a substantially homologous sequence. The purified human BMP-5 proteins are substantially free from other proteinaceous materials with which they are co-produced, as well as from other contaminants.

Purified BMP-5 bovine cartilage/bone proteins of the present invention are produced by culturing a host cell transformed with a DNA sequence comprising the DNA sequence as shown in Table I from nucleotide # 8 to nucleotide # 578 or substantially homologous sequences and recovering and purifying from the culture medium a protein comprising the amino acid sequence as shown in Table I from amino acid # 9 to amino acid # 140 or a substantially homologous sequence. The purified BMP-5 bovine proteins as well as all of the BMP proteins of the invention, are substantially free from other proteinaceous materials with which they are co-produced, as well as from other contaminants.

Purified human BMP-6 proteins may be produced by culturing a host cell transformed with the DNA sequence of Table IV. The expressed proteins are isolated and purified from the culture medium. Purified human BMP-6 proteins of the invention are expected to be characterized by an amino acid sequence comprising amino acid #382 to #513 as set forth in Table IV. These purified BMP-6 human cartilage/bone proteins of the present invention are therefore produced by culturing a host cell transformed with a DNA sequence comprising nucleotide #160 to nucleotide #1698 as set forth



in Table IV or substantially homologous sequence  
operatively linked to a heterologous regulatory  
control sequence and recovering, isolating and  
purifying from the culture medium a protein  
5 comprising amino acid #382 to amino acid #513 as  
set forth in Table IV or a substantially homologous  
sequence.

Further embodiments may utilize the DNA  
sequence comprising the nucleotides encoding amino  
10 acids #382 - #513. Purified human BMP-6 proteins  
may therefore be produced by culturing a host cell  
transformed with the DNA sequence comprising  
nucleotide #1303 to #1698 as set forth in Table IV  
or substantially homologous sequences operatively  
15 linked to a heterologous regulatory control  
sequence and recovering and purifying from the  
culture medium a protein comprising amino acid #382  
to #513 as set forth in Table IV or a substantially  
homologous sequence. The purified human BMP-6  
20 proteins are substantially free from other  
proteinaceous materials with which they are co-  
produced, as well as from other contaminants.

Purified BMP-6 bovine cartilage/bone protein  
of the present invention are produced by culturing  
25 a host cell transformed with a DNA sequence  
comprising nucleotide #361 to nucleotide #666 as  
set forth in Table II or substantially homologous  
sequences and recovering from the culture medium a  
protein comprising amino acid #121 to amino acid  
30 #222 as set forth in Table II or a substantially  
homologous sequence. In another embodiment the  
bovine protein is produced by culturing a host cell  
transformed with a sequence comprising nucleotide  
#289 to #666 of Table II and recovering and  
35 purifying a protein comprising amino acid #97 to

amino acid #222. The purified BMP-6 bovine proteins are substantially free from other proteinaceous materials with which they are co-produced, as well as from other contaminants.

5 Purified human BMP-7 proteins may be produced by culturing a host cell transformed with the DNA sequence of Table V. The expressed proteins are isolated and purified from the culture medium. Purified human BMP-7 proteins are expected to be  
10 characterized by an amino acid sequence comprising amino acid #300-#431 as shown in Table V. These purified BMP-7 human cartilage/bone proteins of the present invention are therefore produced by culturing a host cell transformed with a DNA  
15 sequence comprising nucleotide #97 to nucleotide #1389 as shown in Table V or substantially homologous sequences operatively linked to a heterologous regulatory control sequence and recovering, isolating and purifying from the  
20 culture medium a protein comprising the amino acid sequence as shown in Table V from amino acid #300 to amino acid #431 or a substantially homologous sequence.

Further embodiments may utilize the DNA  
25 sequence comprising the nucleotides encoding amino acids #300 - #431. Purified BMP-7 proteins may be produced by culturing a host cell transformed with a DNA comprising the DNA sequence as shown in Table V from nucleotide #994 - #1389 or substantially  
30 homologous sequences operatively linked to a heterologous regulatory control sequence and recovering, and purifying from the culture medium a protein comprising the amino acid sequence as shown in Table V from amino acid #300 to amino acid #431  
35 or a substantially homologous sequence. The

purified human BMP-7 proteins are substantially free from other proteinaceous materials from which they are co-produced, as well as from other contaminants.

5 BMP-5, BMP-6 and BMP-7 proteins may be further characterized by the ability to demonstrate cartilage and/or bone formation activity. This activity may be demonstrated, for example, in the rat bone formation assay as described in Example  
10 III. It is further contemplated that these proteins demonstrate activity in the assay at a concentration of 10  $\mu$ g - 500  $\mu$ g/gram of bone formed. The proteins may be further characterized by the ability of 1  $\mu$ g to score at least +2 in this  
15 assay using either the original or modified scoring method described further herein below.

BMP-5, BMP-6 and BMP-7 proteins may be further characterized by an apparent molecular weight of 28,000-30,000 daltons as determined by sodium  
20 dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE). Under reducing conditions in SDS-PAGE the protein electrophoresis with a molecular weight of approximately 14,000-20,000 daltons.

The proteins provided herein also include  
25 factors encoded by the sequences similar to those of Tables I - V but into which modifications are naturally provided (e.g. allelic variations in the nucleotide sequence which may result in amino acid changes in the polypeptide) or deliberately  
30 engineered. Similarly, synthetic polypeptides which wholly or partially duplicate continuous sequences of the amino acid residues of Tables I-V are encompassed by the invention. These sequences, by virtue of sharing primary, secondary,  
35 or tertiary structural and conformational

characteristics with other cartilage/bone proteins of th invention may possess bone and/or cartilage growth factor biological properties in common therewith. Thus, they may be employed as  
5 biologically active substitutes for naturally-occurring proteins in therapeutic processes.

Other specific mutations of the sequences of the proteins of the invention described herein involve modifications of a glycosylation site.  
10 These modification may involve O-linked or N-linked glycosylation sites. For instance, the absence of glycosylation or only partial glycosylation results from amino acid substitution or deletion at the asparagine-linked glycosylation recognition sites  
15 present in the sequences of the proteins of the invention, as shown in Table I - V. The asparagine-linked glycosylation recognition sites comprise tripeptide sequences which are specifically recognized by appropriate cellular  
20 glycosylation enzymes. These tripeptide sequences are either asparagine-X-threonine or asparagine-X-serine, where X is usually any amino acid. A variety of amino acid substitutions or deletions at one or both of the first or third amino acid  
25 positions of a glycosylation recognition site (and/or amino acid deletion at the second position) results in non-glycosylation at the modified tripeptide sequence. Expression of such altered nucleotide sequences produces variants which are  
30 not glycosylated at that site.

The present invention also encompasses the novel DNA sequences, free of association with DNA sequences encoding other proteinaceous materials, and coding on expression for the proteins of the  
35 invention. These DNA sequences include those

depicted in Tables I - V in a 5' to 3' direction. Further included are those sequences which hybridize under stringent hybridization conditions [see, T. Maniatis et al, Molecular Cloning (A Laboratory Manual)], Cold Spring Harbor Laboratory (1982), pages 387 to 389] to the DNA sequence of Tables I - V and demonstrate cartilage and/or bone formation activity in the rat bone formation assay. An example of one such stringent hybridization condition is hybridization at [6- 4 x SSC at 65°C, followed by a washing in 0.1 x SCC at 65°C for an hour. Alternatively, an exemplary stringent hybridization condition is in 50% formamide, 4 x SCC at 42°C.

Similarly, DNA sequences which encode proteins similar to the protein encoded by the sequences of Tables I - V, but which differ in codon sequence due to the degeneracies of the genetic code or allelic variations (naturally-occurring base changes in the species population which may or may not result in an amino acid change) also encode the proteins of the invention described herein. Variations in the DNA sequences of Tables I - V which are caused by point mutations or by induced modifications (including insertion, deletion, and substitution) to enhance the activity, half-life or production of the polypeptides encoded thereby are also encompassed in the invention.

In a further aspect, the invention provides a method for obtaining related human proteins or other mammalian BMP-5, BMP-6 and BMP-7 proteins. One method for obtaining such proteins entails, for instance, utilizing the human BMP-5, BMP-6 and BMP-7 coding sequence disclosed herein to probe a human genomic library using standard techniques for

the human gene or fragments thereof. Sequences thus identified may also be used as probes to identify a human cell line or tissue which synthesizes the analogous cartilage/bone protein.

5 A cDNA library is synthesized and screened with probes derived from the human or bovine coding sequences. The human sequence thus identified is transformed into a host cell, the host cell is cultured and the protein recovered, isolated and

10 purified from the culture medium. The purified protein is predicted to exhibit cartilage and/or bone formation activity in the rat bone formation assay of Example III.

Another aspect of the present invention

15 provides a novel method for producing the BMP-5, BMP-6 and BMP-7 proteins of the invention. The method of the present invention involves culturing a suitable cell or cell line, which has been transformed with a DNA sequence as described above

20 coding for expression of a protein of the invention, under the control of known regulatory sequences. Regulatory sequences include promoter fragments, terminator fragments and other suitable sequences which direct the expression of the

25 protein in an appropriate host cell. Methods for culturing suitable cell lines are within the skill of the art. The transformed cells are cultured and the BMP proteins expressed thereby are recovered, isolated and purified from the culture medium

30 using purification techniques known to those skilled in the art. The purified BMP proteins are substantially free from other proteinaceous materials with which they are co-produced, as well as other contaminants. Purified BMP proteins of

35 the invention are substantially free from

materials with which the proteins of the invention exist in nature.

Suitable cells or cell lines may be mammalian cells, such as Chinese hamster ovary cells (CHO).  
5 The selection of suitable mammalian host cells and methods for transformation, culture, amplification, screening and product production and purification are known in the art. See, e.g., Gething and Sambrook, Nature, 293:620-625 (1981), or  
10 alternatively, Kaufman et al, Mol. Cell. Biol., 5(7):1750-1759 (1985) or Howley et al, U.S. Patent 4,419,446. Other suitable mammalian cell lines include but are not limited to the monkey COS-1 cell line and the CV-1 cell line.

15 Bacterial cells may also be suitable hosts. For example, the various strains of E. coli (e.g., HB101, MC1061) are well-known as host cells in the field of biotechnology. Various strains of B. subtilis, Pseudomonas, other bacilli and the  
20 like may also be employed in this method.

Many strains of yeast cells known to those skilled in the art may also be available as host cells for expression of the polypeptides of the present invention. Additionally, where desired,  
25 insect cells may be utilized as host cells in the method of the present invention. See, e.g. Miller et al, Genetic Engineering, 8:277-298 (Plenum Press 1986) and references cited therein.

Another aspect of the present invention  
30 provides vectors for use in the method of expression of the proteins of the invention. The vectors contain the novel DNA sequences which code for the BMP-5, BMP-6 and BMP-7 proteins of the invention. Additionally, the vectors also contain  
35 appropriate expression control sequences permitting

expression of the protein sequences. Alternatively, vectors incorporating truncated or modified sequences as described above are also embodiments of the present invention and useful in the production of the proteins of the invention. The vectors may be employed in the method of transforming cell lines and contain selected regulatory sequences in operative association with the DNA coding sequences of the invention which are capable of directing the replication and expression thereof in selected host cells. Useful regulatory sequences for such vectors are known to those skilled in the art and may be selected depending upon the selected host cells. Such selection is routine and does not form part of the present invention. Host cells transformed with such vectors and progeny thereof for use in producing BMP-5, BMP-6 and BMP-7 proteins are also provided by the invention.

One skilled in the art can construct mammalian expression vectors by employing the DNA sequences of the invention and known vectors, such as pCD [Okayama et al., Mol. Cell Biol., 2:161-170 (1982)] and pJL3, pJL4 [Gough et al., EMBO J., 4:645-653 (1985)]. Similarly, one skilled in the art could manipulate the sequences of the invention by eliminating or replacing the mammalian regulatory sequences flanking the coding sequence with bacterial sequences to create bacterial vectors for intracellular or extracellular expression by bacterial cells. For example, the coding sequences could be further manipulated (e.g. ligated to other known linkers or modified by deleting non-coding sequences therefrom or altering nucleotides therein by other known



techniques). The modified coding sequence could then be inserted into a known bacterial vector using procedures such as described in T. Taniguchi et al., Proc. Natl Acad. Sci. USA, 77:5230-5233 (1980). This exemplary bacterial vector could then be transformed into bacterial host cells and a protein of the invention expressed thereby. For a strategy for producing extracellular expression of a cartilage and/or bone protein of the invention in bacterial cells., see, e.g. European patent application EPA 177,343.

Similar manipulations can be performed for the construction of an insect vector [See, e.g. procedures described in published European patent application 155,476] for expression in insect cells. A yeast vector could also be constructed employing yeast regulatory sequences for intracellular or extracellular expression of the factors of the present invention by yeast cells. [See, e.g., procedures described in published PCT application WO86/00639 and European patent application EPA 123,289].

A method for producing high levels of a protein of the invention from mammalian cells involves the construction of cells containing multiple copies of the heterologous gene encoding proteins of the invention. The heterologous gene may be linked to an amplifiable marker, e.g. the dihydrofolate reductase (DHFR) gene for which cells containing increased gene copies can be selected for propagation in increasing concentrations of methotrexate (MTX) according to the procedures of Kaufman and Sharp, J. Mol. Biol., 159:601-629 (1982). This approach can be employed with a number of different cell types.

For instance, a plasmid containing a DNA sequence for a protein of the invention in operative association with other plasmid sequences enabling expression thereof and the DHFR expression plasmid pAdA26SV(A)3 [Kaufman and Sharp, Mol. Cell. Biol., 2:1304 (1982)] may be co-introduced into DHFR-deficient CHO cells, DUKX-BII, by calcium phosphate coprecipitation and transfection, electroporation or protoplast fusion.

DHFR expressing transformants are selected for growth in alpha media with dialyzed fetal calf serum, and subsequently selected for amplification by growth in increasing concentrations of MTX (sequential steps in 0.02, 0.2, 1.0 and 5uM MTX) as described in Kaufman et al., Mol Cell Biol., 5:1750 (1983). Protein expression should increase with increasing levels of MTX resistance.

Transformants are cloned, and the proteins of the invention are recovered, isolated, and purified from the culture medium. Characterization of expressed proteins may be carried out using standard techniques. For instance, characterization may include pulse labeling with [<sup>35</sup>S] methionine or cysteine, or polyacrylamide gel electrophoresis. Biologically active protein expression is monitored by the Rosen-modified Sampath - Reddi rat bone formation assay described above in Example III. Similar procedures can be followed to produce other related proteins.

A protein of the present invention, which induces cartilage and/or bone formation in circumstances where bone and/or cartilage is not normally formed, has application in the healing of bone fractures and cartilage defects in humans and other animals. A preparation employing a protein

of the invention may have prophylactic use in closed as well as open fracture reduction and also in the improved fixation of artificial joints. De novo bone formation induced by an osteogenic agent contributes to the repair of congenital, trauma induced, or oncologic resection induced craniofacial defects, and also is useful in cosmetic plastic surgery. A protein of the invention may be used in the treatment of periodontal disease, and in other tooth repair processes. Such agents may provide an environment to attract bone-forming cells, stimulate growth of bone-forming cells or induce differentiation of progenitors of bone-forming cells. A variety of osteogenic, cartilage-inducing and bone inducing factors have been described. See, e.g. European Patent Applications 148,155 and 169,016 for discussions thereof.

The proteins of the invention may also be used in wound healing and related tissue repair. The types of wounds include, but are not limited to burns, incisions and ulcers. See, e.g. PCT Publication WO84/01106 for discussion of wound healing and related tissue repair.

A further aspect of the invention includes therapeutic methods and composition for repairing fractures and other conditions related to bone and/or cartilage defects or periodontal diseases. In addition, the invention comprises therapeutic methods and compositions for wound healing and tissue repair. Such compositions comprise a therapeutically effective amount of at least one of the BMP proteins BMP-5, BMP-6 and BMP-7 of the invention in admixture with a pharmaceutically acceptable vehicle, carrier or

matrix.

It is expected that the proteins of the invention may act in concert with r p rhaps synergistically with one another or with other  
5 related proteins and growth factors. Therapeutic methods and compositions of the invention therefore comprise one or more of the proteins of the present invention. Further therapeutic methods and compositions of the invention therefore  
10 comprise a therapeutic amount of at least one protein of the invention with a therapeutic amount of at least one of the other "BMP" proteins BMP-1, BMP-2, BMP-3 and BMP-4 disclosed in co-owned  
15 Published International Applications WO88/00205 and WO89/10409 as mentioned above. Such methods and compositions of the invention may comprise proteins of the invention or portions thereof in combination with the above-mentioned "BMP" proteins or portions thereof.

20 Such combination may comprise individual separate molecules of the proteins or heteromolecules such as heterodimers formed by portions of the respective proteins. For example, a method and composition of the invention may  
25 comprise a BMP protein of the present invention or a portion thereof linked with a portion of another "BMP" protein to form a heteromolecule.

Further therapeutic methods and compositions of the invention comprise the proteins of the  
30 invention or portions thereof in combination with other agents beneficial to the treatment of the bone and/or cartilage defect, wound, or tissue in question. These agents include various growth factors such as epidermal growth factor (EGF),  
35 fibroblast growth factor (FGF), platelet derived

growth factor (PDGF), transforming growth factors (TGF- $\alpha$  and TGF- $\beta$ ), K-fibroblast growth factor (kFGF), parathyroid hormone (PTH), leukemia inhibitory factor (LIF/HILDA, DIA) and insulin-like growth factor (IGF-I and IGF-II). Portions of these agents may also be used in compositions of the invention.

The preparation and formulation of such physiologically acceptable protein compositions, having due regard to pH, isotonicity, stability and the like, is within the skill of the art. The therapeutic compositions are also presently valuable for veterinary applications due to the apparent lack of species specificity in cartilage and bone growth factor proteins. Domestic animals and thoroughbred horses in addition to humans are desired patients for such treatment with the proteins of the present invention.

The therapeutic method includes administering the composition topically, systemically, or locally as an implant or device. When administered, the therapeutic composition for use in this invention is, of course, in a pyrogen-free, physiologically acceptable form. Further, the composition may desirably be encapsulated or injected in a viscous form for delivery to the site of cartilage and/or bone or tissue damage. Topical administration may be suitable for wound healing and tissue repair.

Preferably for bone and/or cartilage formation, the composition would include a matrix capable of delivering the BMP proteins of the invention to the site of bone and/or cartilage damage, providing a structure for the developing bone and cartilage and optimally capable of being resorbed into the body. The matrix may provide

slow release of the BMP proteins or other factors comprising the composition. Such matrices may be formed of materials presently in use for other implanted medical applications.

5       The choice of matrix material is based on biocompatibility, biodegradability, mechanical properties, cosmetic appearance and interface properties. The particular application of the compositions of the invention will define the  
10       appropriate formulation. Potential matrices for the compositions may be biodegradable and chemically defined calcium sulfate, tricalciumphosphate, hydroxyapatite, polylactic acid and polyanhydrides. Other potential  
15       materials are biodegradable and biologically well defined, such as bone or dermal collagen. Further matrices are comprised of pure proteins or extracellular matrix components. Other potential  
20       matrices are nonbiodegradable and chemically defined, such as sintered hydroxyapatite, bioglass, aluminates, or other ceramics. Matrices may be comprised of combinations of any of the above mentioned types of material, such as  
25       polylactic acid and hydroxyapatite or collagen and tricalciumphosphate. The bioceramics may be altered in composition, such as in calcium-aluminate-phosphate and processing to alter pore size, particle size, particle shape, and biodegradability.

30       The dosage regimen will be determined by the attending physician considering various factors which modify the action of the proteins of the invention. Factors which may modify the action of the proteins of the invention include the amount of  
35       bone weight desired to be formed, the site of bone

damage, the condition of the damaged bone, the size of a wound, type of damaged tissue, the patient's age, sex, and diet, the severity of any infection, time of administration and other clinical factors.

5 The dosage may vary with the type of matrix used in the reconstitution and the type or types of bone and/or cartilage proteins present in the composition. The addition of other known growth factors, such as EGF, PDGF, TGF- $\alpha$ , TGF- $\beta$ , and IGF-I

10 and IGF-II to the final composition, may also effect the dosage.

Progress can be monitored by periodic assessment of cartilage and/or bone growth and/or repair. The progress can be monitored, for

15 example, using x-rays, histomorphometric determinations and tetracycline labeling.

The following examples illustrate practice of the present invention in recovering and characterizing bovine cartilage and/or bone

20 proteins of the invention and employing these proteins to recover the corresponding human protein or proteins and in expressing the proteins via recombinant techniques.

#### EXAMPLE I

##### 25 Isolation of Bovine Cartilage/Bone Inductive Protein

Ground bovine bone powder (20-120 mesh, Helitrex) is prepared according to the procedures of M. R. Urist et al., Proc. Natl Acad. Sci USA,

30 70:3511 (1973) with elimination of some extraction steps as identified below. Ten kgs of the ground powder is demineralized in successive changes of 0.6N

HCl at 4°C over a 48 hour period with vigorous

stirring. The resulting suspension is extracted for 16 hours at 4°C with 50 liters of 2M  $\text{CaCl}_2$  and 10mM ethylen diamine-tetraacetic acid [EDTA], and followed by extraction for 4 hours in 50 liters of 0.5M EDTA. The residue is washed three times with distilled water before its resuspension in 20 liters of 4M guanidine hydrochloride [GuCl], 20mM Tris (pH 7.4), 1mM N-ethylmaleimide, 1mM iodoacetamide, 1mM phenylmethylsulfonyl fluoride as described in Clin. Orthop. Rel. Res., 171: 213 (1982). After 16 to 20 hours the supernatant is removed and replaced with another 10 liters of GuCl buffer. The residue is extracted for another 24 hours.

The crude GuCl extracts are combined, concentrated approximately 20 times on a Pellicon apparatus with a 10,000 molecular weight cut-off membrane, and then dialyzed in 50mM Tris, 0.1M NaCl, 6M urea (pH 7.2), the starting buffer for the first column. After extensive dialysis the protein is loaded on a 4 liter DEAE cellulose column and the unbound fractions are collected.

The unbound fractions are concentrated and dialyzed against 50mM NaAc, 50mM NaCl (pH 4.6) in 6M urea. The unbound fractions are applied to a carboxymethyl cellulose column. Protein not bound to the column is removed by extensive washing with starting buffer, and the material containing protein having bone and/or cartilage formation activity as measured by the Rosen-modified Sampath-Reddi assay (described in Example III below) desorbed from the column by 50mM NaAc, 0.25mM NaCl, 6M urea (pH 4.6). The protein from this step elution is concentrated 20- to 40- fold, then diluted 5 times with 80mM  $\text{KPO}_4$ , 6M urea (pH 6.0).



The pH of the solution is adjusted to 6.0 with 500mM  $K_2HPO_4$ . The sample is applied to an hydroxylapatite column (LKB) equilibrated in 80mM  $KPO_4$ , 6M urea (pH6.0) and all unbound protein is removed by washing the column with the same buffer. Protein having bone and/or cartilage formation activity is eluted with 100mM  $KPO_4$  (pH7.4) and 6M urea.

The protein is concentrated approximately 10 times, and solid NaCl added to a final concentration of 0.15M. This material is applied to a heparin - Sepharose column equilibrated in 50mM  $KPO_4$ , 150mM NaCl, 6M urea (pH7.4). After extensive washing of the column with starting buffer, a protein with bone and/or cartilage inductive activity is eluted by 50mM  $KPO_4$ , 700mM NaCl, 6M urea (pH7.4). This fraction is concentrated to a minimum volume, and 0.4ml aliquots are applied to Superose 6 and Superose 12 columns connected in series, equilibrated with 4M  $GuCl$ , 20mM Tris (pH7.2) and the columns developed at a flow rate of 0.25ml/min. The protein demonstrating bone and/or cartilage inductive activity corresponds to an approximate 30,000 dalton protein.

The above fractions from the superose columns are pooled, dialyzed against 50mM NaAc, 6M urea (pH4.6), and applied to a Pharmacia MonoS HR column. The column is developed with a gradient to 1.0M NaCl, 50mM NaAc, 6M urea (pH4.6). Active bone and/or cartilage formation fractions are pooled. The material is applied to a 0.46 x 25cm Vydac C4 column in 0.1% TFA and the column developed with a gradient to 90% acetonitrile, 0.1% TFA (31.5% acetonitrile, 0.1% TFA to 49.5% acetonitrile, 0.1% TFA in 60 minutes at 1ml per minute). Active

material is eluted at approximately 40-44% acetonitrile. Fractions were assayed for cartilage and/or bone formation activity. The active material is further fractionated on a MonoQ column. The protein is dialyzed against 6M urea, 25mM diethanolamine, pH 8.6 and then applied to a 0.5 by 5 cm MonoQ column (Pharmacia) which is developed with a gradient of 6M urea, 25mM diethanolamine, pH 8.6 and 0.5 M NaCl, 6M urea, 25mM diethanolamine, pH 8.6. Fractions are brought to pH 3.0 with 10% trifluoroacetic acid (TFA). Aliquots of the appropriate fractions are iodinated by one of the following methods: P. J. McConahey et al, Int. Arch. Allergy, 29:185-189 (1966); A. E. Bolton et al, Biochem J., 133:529 (1973); and D. F. Bowen-Pope, J. Biol. Chem., 237:5161 (1982). The iodinated proteins present in these fractions are analyzed by SDS gel electrophoresis.

## EXAMPLE II

### 20 Characterization of Bovine Cartilage/Bone Inductive Factor

#### A. Molecular Weight

Approximately 5µg protein from Example I in 6M urea, 25mM diethanolamine, pH 8.6, approximately 0.3 M NaCl is made 0.1% with respect to SDS and dialyzed against 50 mM Tris/HCl 0.1% SDS pH 7.5 for 16 hrs. The dialyzed material is then electrophoretically concentrated against a dialysis membrane [Hunkapillar et al Meth. Enzymol. 91: 227-236 (1983)] with a small amount of I 125 labelled counterpart. This material (volume approximately 100µl) is loaded onto a 12% polyacrylamide gel and subjected to SDS-PAGE [Laemmli, U.K. Nature, 227:680-685 (1970)] without

reducing the sample with dithiothreitol. The molecular weight is determined relative to prestained molecular weight standards (Bethesda Research Labs). Following autoradiography of the unfixed gel the approximate 28,000-30,000 dalton band is excised and the protein electrophoretically eluted from the gel (Hunkapillar et al supra). Based on similar purified bone fractions as described in the co-pending "BMP" applications described above wherein bone and/or cartilage activity is found in the 28,000-30,000 region, it is inferred that this band comprises bone and/or cartilage inductive fractions.

#### B. Subunit Characterization

The subunit composition of the isolated bovine bone protein is also determined. The eluted protein described above is fully reduced and alkylated in 2% SDS using iodoacetate and standard procedures and reconcentrated by electrophoretic packing. The fully reduced and alkylated sample is then further submitted to SDS-PAGE on a 12% gel and the resulting approximate 14,000-20,000 dalton region having a doublet appearance located by autoradiography of the unfixed gel. A faint band remains at the 28,000-30,000 region. Thus the 28,000-30,000 dalton protein yields a broad region of 14,000-20,000 which may otherwise also be interpreted and described as comprising two broad bands of approximately 14,000-16,000 and 16,000-20,000 daltons.

#### EXAMPLE III

##### Rosen Modified Sampath-Reddi Assay

A modified version of the rat bone

formation assay described in Sampath and Reddi, Proc. Natl. Acad. Sci. U.S.A., 80:6591-6595 (1983) is used to evaluate bone and/or cartilage activity of the proteins of the invention. This modified assay is herein called the Rosen-modified Sampath-Reddi assay. The ethanol precipitation step of the Sampath-Reddi procedure is replaced by dialyzing (if the composition is a solution) or diafiltering (if the composition is a suspension) the fraction to be assayed against water. The solution or suspension is then redissolved in 0.1 % TFA, and the resulting solution added to 20mg of rat matrix. A mock rat matrix sample not treated with the protein serves as a control. This material is frozen and lyophilized and the resulting powder enclosed in #5 gelatin capsules. The capsules are implanted subcutaneously in the abdominal thoracic area of 21 - 49 day old male Long Evans rats. The implants are removed after 7 - 14 days. Half of each implant is used for alkaline phosphatase analysis [See, A. H. Reddi et al., Proc. Natl Acad Sci., 69:1601 (1972)].

The other half of each implant is fixed and processed for histological analysis. Glycolmethacrylate sections (1 $\mu$ m) are stained with Von Kossa and acid fuchsin or toluidine blue to score the amount of induced bone and cartilage formation present in each implant. The terms +1 through +5 represent the area of each histological section of an implant occupied by new bone and/or cartilage cells and newly formed bone and matrix. Two scoring methods are herein described. In the first scoring method a score of +5 indicates that greater than 50% of the implant is new bone and/or cartilage produced as a direct result of protein in

the implant. A score of +4, +3, +2 and +1 would indicate that greater than 40%, 30%, 20% and 10% respectively of the implant contains new cartilage and/or bone. The second scoring method (which hereinafter may be referred to as the modified scoring method) is as follows: three non-adjacent sections are evaluated from each implant and averaged. "+/-" indicates tentative identification of cartilage or bone; "+1" indicates >10% of each section being new cartilage or bone; "+2", >25%; "+3", >50%; "+4", ~75%; "+5", >80%. The scores of the individual implants are tabulated to indicate assay variability.

It is contemplated that the dose response nature of the cartilage and/or bone inductive protein containing samples of the matrix samples will demonstrate that the amount of bone and/or cartilage formed increases with the amount of cartilage/bone inductive protein in the sample. It is contemplated that the control samples will not result in any bone and/or cartilage formation.

As with other cartilage and/or bone inductive proteins such as the above-mentioned "BMP" proteins, the bone and/or cartilage formed is expected to be physically confined to the space occupied by the matrix. Samples are also analyzed by SDS gel electrophoresis and isoelectric focusing followed by autoradiography. The activity is correlated with the protein bands and pI. To estimate the purity of the protein in a particular fraction an extinction coefficient of 1 OD/mg-cm is used as an estimate for protein and the protein is run on SDS-PAGE followed by silver staining or radioiodination and autoradiography.

## EXAMPLE IV

A. Bovine Prot in Composition

The gel slice of th approximate 14,000-20,000 dalton region described in Example IIB is fixed with methanol-acetic acid-water using standard procedures, briefly rinsed with water, then neutralized with 0.1M ammonium bicarbonate. Following dicing the gel slice with a razor blade, the protein is digested from the gel matrix by adding 0.2 µg of TPCK-treated trypsin (Worthington) and incubating the gel for 16 hr. at 37 degrees centigrade. The resultant digest is then subjected to RPHPLC using a C4 Vydac RPHPLC column and 0.1% TFA-water 0.1% TFA water-acetonitrile gradient. The resultant peptide peaks were monitored by UV absorbance at 214 and 280 nm and subjected to direct amino terminal amino acid sequence analysis using an Applied Biosystems gas phase sequenator (Model 470A). One tryptic fragment is isolated by standard procedures having the following amino acid sequence as represented by the amino acid standard three-letter symbols and where "Xaa" indicates an unknown amino acid the amino acid in parentheses indicates uncertainty in the sequence:

Xaa-His-Glu-Leu-Tyr-Val-Ser-Phe-(Ser)

The following four oligonucleotide probes are designed on the basis of the amino acid sequence of the above-identified tryptic fragment and synthesized on an automated DNA synthesizer.

PROBE #1: GTRCTYGANATRCANTC

PROBE #2: GTRCTYGANATRCANAG

PROBE #3: GTRCTYAAAYATRCANTC

PROBE #4: GTRCTYAAAYATRCANAG

5 The standard nucleotide symbols in the above identified probes are as follows: A,adenosine; C,cytosine; G,guanine; T,thymine; N, adenosine or cytosine or guanine or thymine; R,adenosine or guanine; and Y,cytosine or thymine.

10 Each of the probes consists of pools of oligonucleotides. Because the genetic code is degenerate (more than one codon can code for the same amino acid), a mixture of oligonucleotides is synthesized that contains all possible nucleotide sequences encoding the amino acid sequence of the tryptic. These probes are radioactively labeled  
15 and employed to screen a bovine cDNA library as described below.

#### B. Bovine BMP-5

Poly(A) containing RNA is isolated by oligo(dT) cellulose chromatography from total RNA  
20 isolated from fetal bovine bone cells by the method of Gehron-Robey et al in Current Advances in Skeletogenesis, Elsevier Science Publishers (1985). The total RNA was obtained from Dr. Marion Young, National Institute of Dental Research, National  
25 Institutes of Health. A cDNA library is made in lambda gt10 (Toole et al supra) and plated on 50 plates at 8000 recombinants per plate. These recombinants (400,000) are screened on duplicate nitrocellulose filters with a combination of Probes  
30 1, 2, 3, and 4 using the Tetramethylammonium chloride (TMAC) hybridization procedure [see Wozney et al Science, 242: 1528-1534 (1988)]. Twenty-

eight positives are obtained and are replated for secondaries. Duplicate nitrocellulose replicas again are made. One set of filters are screened with Probes #1 and #2; the other with Probes #3 and #4. Six positives are obtained on the former, 21 positives with the latter. One of the six, called HEL5, is plaque purified, a phage plate stock made, and bacteriophage DNA isolated. This DNA is digested with EcoRI and subcloned into M13 and pSP65 (Promega Biotec, Madison, Wisconsin) [Melton, et al. Nucl. Acids Res. 12: 7035-7056 (1984)]. The DNA sequence and derived amino acid sequence of this fragment is shown in Table I.

DNA sequence analysis of this fragment in M13 indicates that it encodes the desired tryptic peptide sequence set forth above, and this derived amino acid sequence is preceded by a basic residue (Lys) as predicted by the specificity of trypsin. The underlined portion of the sequence in Table I from amino acid #42 to #48 corresponds to the tryptic fragment identified above from which the oligonucleotide probes are designed. The derived amino acid sequence Ser-Gly-Ser-His-Gln-Asp-Ser-Ser-Arg as set forth in Table I from amino acid #15 to #23 is noted to be similar to a tryptic fragment sequence Ser-Thr-Pro-Ala-Gln-Asp-Val-Ser-Arg found in the 28,000 - 30,000 dalton purified bone preparation as described in the "BMP" Publications WO88/00205 and WO89/10409 mentioned above. This fragment set forth in Table I is a portion of the DNA sequence which encodes a bovine BMP-5 protein. The DNA sequence shown in Table I indicates an open reading frame from the 5' end of the clone of 420 base pairs, encoding a partial peptide of 140 amino acid residues (the first 7 nucleotides are of the



adaptors used in the cloning procedure). An in-frame stop codon (TAA) indicates that this clone encodes the carboxy-terminal part of bovine BMP-5.

TABLE I

1	TCTAGAGGTGAGAGCAGCCAACAAGAGAAAAAATCAAAACCGCAATAAATCCGGCTCTCAT LeuGluValArgAlaAlaAsnLysArgLysAsnGlnAsnArgAsnLys <u>SerGlySerHis</u> (1) (15)	61
62	CAGGACTCCTCTAGAATGTCCAGTGTTGGAGATTATAACACCAGTGAACAAAAACAAGCC <u>GlnAspSerSerArgMetSerSerValGlyAspTyrAsnThrSerGluGlnLysGlnAla</u> (23)	12
122	TGTAAAAGCATGAACTCTATGTGAGTTTCCGGGATCTGGGATGGCAGGACTGGATTATA CysLysLys <u>HisGluLeuTyrValSerPheArgAspLeuGlyTrpGlnAspTrpIleIle</u> (42) (48)	18
182	GCACCAGAAGGATATGCTGCATTTTATTGTGATGGAGAATGTTCTTTTCCACTCAATGCC AlaProGluGlyTyrAlaAlaPheTyrCysAspGlyGluCysSerPheProLeuAsnAla	24
242	CATATGAATGCCACCAATCATGCCATAGTTCAGACTCTGGTTCACCTGATGTTTCCTGAC HisMetAsnAlaThrAsnHisAlaIleValGlnThrLeuValHisLeuMetPheProAsp	30
302	CACGTACCAAAGCCTTGCTGCGCGACAAACAACTAAATGCCATCTCTGTGTTGTACTTT HisValProLysProCysCysAlaThrAsnLysLeuAsnAlaIleSerValLeuTyrPhe	36
362	GATGACAGCTCCAATGTCATTTTGAAAAAGTACAGAAATATGGTCGTGCGTTCGTGTGGT AspAspSerSerAsnValIleLeuLysLysTyrArgAsnMetValValArgSerCysGly	42
422	TGCCACTAATAGTGCATAATAATGGTAATAAGAAAAAAGATCTGTATGGAGGTTTATGA CysHisEnd (140)	48
481	CTACAATAAAAAATATCTTTCGGATAAAAGGGGAATTTAATAAAATTAGTCTGGCTCATT	54
541	TCATCTCTGTAACTATGTACAAGAGCATGTATATAGT	578

C. Bovine BMP-6

5 The remaining positive clones (the second set containing 21 positives) isolated with Probes #1, #2, #3, and #4 described above are screened with HEL5 and a further clone is identified that hybridizes under reduced hybridization conditions [5x SSC, 0.1% SDS, 5X Denhardt's, 100 µg/ml salmon sperm DNA standard hybridization buffer (SHB) at 65°C, wash in 2XSSC 0.1% SDS at 65°C]. This clone is plaque purified, a phage plate stock made and bacteriophage DNA isolated. The DNA sequence and derived amino acid sequence of a portion of this clone is shown in Table II. This sequence represents a portion of the DNA sequence encoding a bovine BMP-6 cartilage/bone protein of the invention.

10 The first underlined portion of the sequence in Table II from amino acid #97 - amino acid #105 corresponds to the tryptic fragment found in the 28,000-30,000 dalton purified bovine bone preparation (and its reduced form at approximately 18,000-20,000 dalton reduced form) as described in the "BMP" Publications WO88/00205 and WO89/10409 mentioned above. The second underlined sequence in Table II from amino acid #124 - amino acid #130 corresponds to the tryptic fragment identified above from which the oligonucleotide probes are designed.

25 The DNA sequence of Table II indicates an open reading frame of 666 base pairs starting from the 5' end of the sequence of Table II, encoding a partial peptide of 222 amino acid residues. An in-frame stop codon (TGA) indicates that this clone encodes the carboxy-terminal part of a bovine BMP-6

5 protein. Based on knowledge of other BMP proteins and other proteins in the TGF- $\beta$  family, it is predicted that the precursor polypeptide would be cleaved at the three basic residues (ArgArgArg) to yield a mature peptide beginning with residue 90 or 91 of the sequence of Table II.

TABLE II

9	18	27	36	45	54
CTG CTG GGC ACG CGT GCT GTG TGG GGC TCA GAG GCG GGC TGG CTG GAG TTT GAC Leu Leu Gly Thr Arg Ala Val Trp Ala Ser Glu Ala Gly Trp Leu Glu Phe Asp (1)	63	72	81	90	99
ATC ACG GGC ACC AGC AAC CTG TGG GTC CTG ACT CCG CAG CAC AAC ATG GGG CTG Ile Thr Ala Thr Ser Asn Leu Trp Val Leu Thr Pro Gln His Asn MET Gly Leu	117	126	135	144	153
CAG CTG AGC GTG GTC ACG CGT GAT GGG CTC AGC ATC AGC OCT GGG GCG GCG GCG Gln Leu Ser Val Val Thr Arg Asp Gly Leu Ser Ile Ser Pro Gly Ala Ala Gly	171	180	189	198	207
CTG GTG GGC AGG GAC GGC CCC TAC GAC AAG CAG CCC TTC ATG GTG GCG TTC TTC Leu Val Gly Arg Asp Gly Pro Tyr Asp Lys Gln Pro Phe MET Val Ala Phe Phe	225	234	243	252	261
AAG GGC AGT GAG GTC CAC GTG CCG AGT GGC CCG TCG GCG CCC GGG CCG CCG CCG Lys Ala Ser Glu Val His Val Arg Ser Ala Arg Ser Ala Pro Gly Arg Arg Arg	279	288	297	306	315
CAG CAG GGC CCG AAC CCG TCC ACC CCG GGC CAG GAC GTG TCG CCG GCG TCC AGC Gln Gln Ala Arg Asn Arg <u>Ser Thr Pro Ala Gln Asp Val Ser Arg Ala Ser Ser</u> (97)	333	342	351	360	369
GCC TCA GAC TAC AAC AGC AGC GAG CTG AAG ACG GCG TGC CCG AAG CAT GAG CTC Ala Ser Asp Tyr Asn Ser Ser Glu Leu Lys Thr Ala Cys Arg Lys <u>His Glu Leu</u> (121) (124)	387	396	405	414	423
TAC GTG AGC TTC CAG GAC CTG GGG TGG CAG GAC TGG ATC ATT GCG CCC AAG GCG <u>Tyr Val Ser Phe Gln Asp Leu Gly Trp Gln Asp Trp Ile Ile Ala Pro Lys Gly</u> (130)	441	450	459	468	477
TAC GCT GCG AAC TAC TGT GAC GGA GAA TGT TCG TTC OCT CTC AAC GCA CAC ATG Tyr Ala Ala Asn Tyr Cys Asp Gly Glu Cys Ser Phe Pro Leu Asn Ala His MET	495	504	513	522	531
AAC GCT ACC AAC CAT GCG ATC GTG CAG ACC CTG GTT CAC CTC ATG AAC CCC GAG Asn Ala Thr Asn His Ala Ile Val Gln Thr Leu Val His Leu MET Asn Pro Glu					

TABLE II  
(page 2 of 2)

549	558	567	576	585	594
TAC GTC CCC AAA CCG TGC TGC GCG CCC ACG AAA CTG AAC GGC ATC TCG GTG CTC					
Tyr Val Pro Lys Pro Cys Cys Ala Pro Thr Lys Leu Asn Ala Ile Ser Val Leu					
603	612	621	630	639	648
TAC TTC GAC GAC AAC TCC AAT GTC ATC CTG AAG AAG TAC CCG AAC ATG GTC GTA					
Tyr Phe Asp Asp Asn Ser Asn Val Ile Leu Lys Lys Tyr Arg Asn MET Val Val					
657	666	676	686	696	706
					716
CGA GCG TGT GGG TGC CAC TGA CTGGGG TGAGTGGCTG GGGAGGCTGT GCACACACTG CCTGGACTCC					
Arg Ala Cys Gly Cys His					
(222)					
726	736	746	756	766	776
TGGATCAAGT CCGCCTTAAG CCCACAGAGG CCCCCGGGAC ACAGGAGGAG ACCCCGAGGC CACCTTGGGC					786
796	806	816	826	836	846
TGGGGTTGGC CTTTGGGCC AAGCAGAAC CGAAGGGACC CTGTCCGGCC CTTGCTCACA CCGTGAGCGT					856
866	876	886			
TGTGAGTAGC CATGGGGCTC TAGGAAGCAG CACTCGAG					

## EXAMPLE V

A. Human Protein Composition

Human cell lines which synthesize BMP-5 and/or BMP-6 mRNAs are identified in the following manner. RNA is isolated from a variety of human cell lines, selected for poly(A)-containing RNA by chromatography on oligo(dT) cellulose, electrophoresed on a formaldehyde-agarose gel, and transferred to nitrocellulose. A nitrocellulose replica of the gel is hybridized to a single stranded M13 <sup>32</sup>P-labeled probe corresponding to the above mentioned BMP-5 EcoRI-BglII fragment containing nucleotides 1-465 of the sequence of Table I. A strongly hybridizing band is detected in the lane corresponding to the human osteosarcoma cell line U-2OS RNA. Another nitrocellulose replica is hybridized to a single stranded M13 <sup>32</sup>P-labeled probe containing the PstI-SmaI fragment of bovine BMP-6 (corresponding to nucleotides 106-261 of Table II). It is found that several RNA species in the lane corresponding to U-2OS RNA hybridize to this probe.

A cDNA Library is made in the vector lambda ZAP (Stratagene) from U-2OS poly(A)-containing RNA using established techniques (Toole et al.). 750,000 recombinants of this library are plated and duplicate nitrocellulose replicas made. The SmaI fragment of bovine BMP-6 corresponding to nucleotides 259-751 of Table II is labeled by nick-translation and hybridized to both sets of filters in SHB at 65°C. One set of filters is washed under stringent conditions (0.2X SSC, 0.1% SDS at 65°C), the other under reduced stringency conditions (1X SSC, 0.1% SDS at 65°C). Many

duplicate hybridizing recombinants (approximately 162) are noted. 24 are picked and replated for secondaries. Three nitrocellulose replicas are made of each plate. One is hybridized to the BMP-6 SmaI probe, one to a nick-translated BMP-6 PstI-SacI fragment (nucleotides 106-378 of Table II), and the third to the nick-translated BMP-5 XbaI fragments (nucleotides 1-76 of Table I). Hybridization and washes are carried out under stringent conditions.

B. Human BMP-5 Proteins

17 clones that hybridize to the third probe more strongly than to the second probe are plaque purified. DNA sequence analysis of one of these, U2-16, indicates that it encodes human BMP-5. U2-16 was deposited with the American Type Culture Collection (ATCC), Rockville, Maryland on June 22, 1989 under accession number ATCC 68109. This deposit as well as the other deposits described herein are made under the provisions of the Budapest Treaty on the International Recognition of the Deposit of Microorganisms for the Purposes of Patent Procedure and the Regulations thereunder (Budapest Treaty). U2-16 contains an insert of approximately 2.1 Kb. The DNA sequence and derived amino acid sequence of U2-16 is shown below in Table III. This clone is expected to contain all of the nucleotide sequence necessary to encode human BMP-5 proteins. The cDNA sequence of Table III contains an open reading frame of 1362 bp, encoding a protein of 454 amino acids, preceded by a 5' untranslated region of 700 bp with stop codons in all frames, and contains a 3' untranslated region of 90 bp following the in frame stop codon (TAA).



5 This protein of 454 amino acids has a  
molecular weight of approximately 52,000 daltons as  
predicted by its amino acid sequence, and is  
contemplated to represent the primary translation  
product. Based on knowledge of other BMP proteins  
and other proteins within the TGF- $\beta$  family, it is  
10 predicted that the precursor polypeptide would be  
cleaved at the tribasic peptide Lys Arg Lys  
yielding a 132 amino acid mature peptide beginning  
with amino acid #323 "Asn". The processing of BMP-  
5 into the mature form is expected to involve  
dimerization and removal of the N-terminal region  
in a manner analogous to the processing of the  
related protein TGF- $\beta$  [L.E. Gentry, et al., Molec.  
15 & Cell. Biol. 8:4162 (1988); R. Dernyck, et al.,  
Nature 316:701 (1985)].

It is contemplated therefore that the mature  
active species of BMP-5 comprises a homodimer of 2  
polypeptide subunits each subunit comprising amino  
20 acid #323 - #454 with a predicted molecular weight  
of approximately 15,000 daltons. Further active  
BMP-5 species are contemplated, for example,  
proprotein dimers or proprotein subunits linked to  
mature subunits. Additional active species may  
25 comprise amino acid #329 - #454 such species  
including homologous the tryptic sequences found in  
the purified bovine material. Also contemplated  
are BMP-5 proteins comprising amino acids #353-  
#454 thereby including the first conserved  
30 cysteine residue.

The underlined sequence of Table III from  
amino acid #329 to #337 Ser-Ser-Ser-His-Gln-Asp-  
Ser-Ser-Arg shares homology with the bovine  
sequence of Table I from amino acid #15 to #23 as  
35 discussed above in Example IV. Each of these

5 sequences shares homology with a tryptic fragment  
sequence Ser-Thr-Pro-Ala-Gln-Asp-Val-Ser-Arg found  
in the 28,000 - 30,000 dalton purified bone  
preparation (and its reduced form at approximately  
18,000 - 20,000 daltons) as described in the "BMP"  
published applications WO88/00205 and WO89/10409  
mentioned above.

10 The underlined sequence of Table III from  
amino acid #356 to #362 His-Glu-Leu-Tyr-Val-Ser-Phe  
corresponds to the tryptic fragment identified in  
the bovine bone preparation described above from  
which the oligonucleotide probes are designed.

TABLE III

10	20	30	40	50
CTGGTATATT	TGTGCCTGCT	GGAGGTGGAA	TTAACAGTAA	GAAGGAGAAA
60	70	80	90	100
GGGATTGAAT	GGACTTACAG	GAAGGATTTT	AAGTAAATTC	AGGGAAACAC
110	120	130	140	150
ATTTACTTGA	ATAGTACAAC	CTAGAGTATT	ATTTTACACT	AAGACGACAC
160	170	180	190	200
AAAAGATGTT	AAAGTTATCA	CCAAGCTGCC	GGACAGATAT	ATATTCCAAC
210	220	230	240	250
ACCAAGGTGC	AGATCAGCAT	AGATCTGTGA	TTCAGAAATC	AGGATTTGTT
260	270	280	290	300
TTGGAAAGAG	CTCAAGGGTT	GAGAAGAACT	CAAAAGCAAG	TGAAGATTAC
310	320	330	340	350
TTTGGGAACT	ACAGTTTATC	AGAAGATCAA	CTTTTGCTAA	TTCAAATACC
360	370	380	390	400
AAAGGCCTGA	TTATCATAAA	TTCATATAGG	AATGCATAGG	TCATCTGATC
410	420	430	440	450
AAATAATATT	AGCCGTCTTC	TGCTACATCA	ATGCAGCAAA	AACTCTTAAC
460	470	480	490	500
AACTGTGGAT	AATTGGAAAT	CTGAGTTTCA	GCTTTCTTAG	AAATAACTAC
510	520	530	540	550
TCTTGACATA	TTCCAAAATA	TTTAAAATAG	GACAGGAAAA	TCGGTGAGGA
560	570	580	590	600
TGTTGTGCTC	AGAAATGTCA	CTGTCATGAA	AAATAGGTAA	ATTTGTTTTT
610	620	630	640	650
TCAGCTACTG	GGAAACTGTA	CCTCCTAGAA	CCTTAGGTTT	TTTTTTTTTT
660	670	680	690	700
AAGAGGACAA	GAAGGACTAA	AAATATCAAC	TTTGTCTTTT	GGACAAAA

TABLE III  
(page 2 of 4)

701	710	719	728	737
ATG CAT CTG ACT GTA TTT TTA CTT AAG GGT ATT GTG GGT TTC CTC				
MET His Leu Thr Val Phe Leu Leu Lys Gly Ile Val Gly Phe Leu				
(1)				
746	755	764	773	782
TGG AGC TGC TGG GTT CTA GTG GGT TAT GCA AAA GGA GGT TTG GGA				
Trp Ser Cys Trp Val Leu Val Gly Tyr Ala Lys Gly Gly Leu Gly				
791	800	809	818	827
GAC AAT CAT GTT CAC TCC AGT TTT ATT TAT AGA AGA CTA CGG AAC				
Asp Asn His Val His Ser Ser Phe Ile Tyr Arg Arg Leu Arg Asn				
836	845	854	863	872
CAC GAA AGA CGG GAA ATA CAA AGG GAA ATT CTC TCT ATC TTG GGT				
His Glu Arg Arg Glu Ile Gln Arg Glu Ile Leu Ser Ile Leu Gly				
881	890	899	908	917
TTG CCT CAC AGA CCC AGA CCA TTT TCA CCT GGA AAA ATG ACC AAT				
Leu Pro His Arg Pro Arg Pro Phe Ser Pro Gly Lys Gln Ala Ser				
926	935	944	953	962
CAA GCG TCC TCT GCA CCT CTC TTT ATG CTG GAT CTC TAC AAT GCC				
Ser Ala Pro Leu Phe MET Leu Asp Leu Tyr Asn Ala MET Thr Asn				
971	980	989	998	1007
GAA GAA AAT CCT GAA GAG TCG GAG TAC TCA GTA AGG GCA TCC TTG				
Glu Glu Asn Pro Glu Glu Ser Glu Tyr Ser Val Arg Ala Ser Leu				
1016	1025	1034	1043	1052
GCA GAA GAG ACC AGA GGG GCA AGA AAG GGA TAC CCA GCC TCT CCC				
Ala Glu Glu Thr Arg Gly Ala Arg Lys Gly Tyr Pro Ala Ser Pro				
1061	1070	1079	1088	1097
AAT GGG TAT CCT CGT CGC ATA CAG TTA TCT CGG ACG ACT CCT CTG				
Asn Gly Tyr Pro Arg Arg Ile Gln Leu Ser Arg Thr Thr Pro Leu				
1106	1115	1124	1133	1142
ACC ACC CAG AGT CCT CCT CTA GCC AGC CTC CAT GAT ACC AAC TTT				
Thr Thr Gln Ser Pro Pro Leu Ala Ser Leu His Asp Thr Asn Phe				
1151	1160	1169	1178	1187
CTG AAT GAT GCT GAC ATG GTC ATG AGC TTT GTC AAC TTA GTT GAA				
Leu Asn Asp Ala Asp MET Val MET Ser Phe Val Asn Leu Val Glu				
1196	1205	1214	1223	1232
AGA GAC AAG GAT TTT TCT CAC CAG CGA AGG CAT TAC AAA GAA TTT				
Arg Asp Lys Asp Phe Ser His Gln Arg Arg His Tyr Lys Glu Phe				

TABLE III  
(page 3 of 4)

1241	1250	1259	1268	1277
CGA TTT GAT CTT ACC CAA ATT CCT CAT GGA GAG GCA GTG ACA GCA				
Arg Phe Asp Leu Thr Gln Ile Pro His Gly Glu Ala Val Thr Ala				
1286	1295	1304	1313	1322
GCT GAA TTC CGG ATA TAC AAG GAC CGG AGC AAC AAC CGA TTT GAA				
Ala Glu Phe Arg Ile Tyr Lys Asp Arg Ser Asn Asn Arg Phe Glu				
1331	1340	1349	1358	1367
AAT GAA ACA ATT AAG ATT AGC ATA TAT CAA ATC ATC AAG GAA TAC				
Asn Glu Thr Ile Lys Ile Ser Ile Tyr Gln Ile Ile Lys Glu Tyr				
1376	1385	1394	1403	1412
ACA AAT AGG GAT GCA GAT CTG TTC TTG TTA GAC ACA AGA AAG GCC				
Thr Asn Arg Asp Ala Asp Leu Phe Leu Leu Asp Thr Arg Lys Ala				
1421	1430	1439	1448	1457
CAA GCT TTA GAT GTG GGT TGG CTT GTC TTT GAT ATC ACT GTG ACC				
Gln Ala Leu Asp Val Gly Trp Leu Val Phe Asp Ile Thr Val Thr				
1466	1475	1484	1493	1502
AGC AAT CAT TGG GTG ATT AAT CCC CAG AAT AAT TTG GGC TTA CAG				
Ser Asn His Trp Val Ile Asn Pro Gln Asn Asn Leu Gly Leu Gln				
1511	1520	1529	1538	1547
CTC TGT GCA GAA ACA GGG GAT GGA CGC AGT ATC AAC GTA AAA TCT				
Leu Cys Ala Glu Thr Gly Asp Gly Arg Ser Ile Asn Val Lys Ser				
1556	1565	1574	1583	1592
GCT GGT CTT GTG GGA AGA CAG GGA CCT CAG TCA AAA CAA CCA TTC				
Ala Gly Leu Val Gly Arg Gln Gly Pro Gln Ser Lys Gln Pro Phe				
1601	1610	1619	1628	1637
ATG GTG GCC TTC TTC AAG GCG AGT GAG GTA CTT CTT CGA TCC GTG				
MET Val Ala Phe Phe Lys Ala Ser Glu Val Leu Leu Arg Ser Val				
1646	1655	1664	1673	1682
AGA GCA GCC AAC AAA CGA AAA AAT CAA AAC CGC AAT AAA TCC AGC				
Arg Ala Ala Asn Lys Arg Lys Asn Gln Asn Arg Asn Lys <u>Ser Ser</u>				
		(323)		(329)
1691	1700	1709	1718	1727
TCT CAT CAG GAC TCC TCC AGA ATG TCC AGT GTT GGA GAT TAT AAC				
<u>Ser His Gln Asp Ser Ser Arg</u> MET Ser Ser Val Gly Asp Tyr Asn				
		(337)		

TABLE III  
(page 4 f 4)

1736	1745	1754	1763	1772	
ACA AGT GAG CAA AAA CAA GCC TGT AAG AAG CAC GAA CTC TAT GTG					
Thr Ser Glu Gln Lys Gln Ala Cys Lys Lys His Glu Leu Tyr Val					
				(356)	
1781	1790	1799	1808	1817	
AGC TTC CGG GAT CTG GGA TGG CAG GAC TGG ATT ATA GCA CCA GAA					
Ser Phe Arg Asp Leu Gly Trp Gln Asp Trp Ile Ile Ala Pro Glu					
(362)					
1826	1835	1844	1853	1862	
GGA TAC GCT GCA TTT TAT TGT GAT GGA GAA TGT TCT TTT CCA CTT					
Gly Tyr Ala Ala Phe Tyr Cys Asp Gly Glu Cys Ser Phe Pro Leu					
1871	1880	1889	1898	1907	
AAC GCC CAT ATG AAT GCC ACC AAC CAC GCT ATA GTT CAG ACT CTG					
Asn Ala His MET Asn Ala Thr Asn His Ala Ile Val Gln Thr Leu					
1916	1925	1934	1943	1952	
GTT CAT CTG ATG TTT CCT GAC CAC GTA CCA AAG CCT TGT TGT GCT					
Val His Leu MET Phe Pro Asp His Val Pro Lys Pro Cys Cys Ala					
1961	1970	1979	1988	1997	
CCA ACC AAA TTA AAT GCC ATC TCT GTT CTG TAC TTT GAT GAC AGC					
Pro Thr Lys Leu Asn Ala Ile Ser Val Leu Tyr Phe Asp Asp Ser					
2006	2015	2024	2033	2042	
TCC AAT GTC ATT TTG AAA AAA TAT AGA AAT ATG GTA GTA CGC TCA					
Ser Asn Val Ile Leu Lys Lys Tyr Arg Asn MET Val Val Arg Ser					
				(450)	
2051	2060	2070	2080	2090	2100
TGT GGC TGC CAC TAATATTAAA TAATATTGAT AATAACAAAA AGATCTGTAT					
Cys Gly Cys His					
(454)					
2110	2120	2130	2140	2150	
TAAGGTTTAT GGCTGCAATA AAAAGCATAC TTTCAGACAA ACAGAAAAAA AAA					

The tryptic sequence His-Glu-Leu-Tyr-Val-Ser-Phe-(Ser) described above is noted to be similar to the sequence His-Pro-Leu-Tyr-Val-Asp-Phe-Ser found in the bovine and human cartilage/bone protein BMP-2A sequence, for instance as described in Publication WO 88/00205. Human BMP-5 shares homology with other BMP molecules as well as other members of the TGF- $\beta$  superfamily of molecules. The cysteine-rich carboxy-terminal 102 amino acid residues of human BMP-5 shares the following homologies with BMP proteins disclosed herein and in Publications WO 88/00205 and WO 89/10409 described above: 61% identity with BMP-2; 43% identity with BMP-3, 59% identity with BMP-4; 91% identity with BMP-6; and 88% identity with BMP-7. Human BMP-5 further shares the following homologies: 38% identity with TGF- $\beta$ 3; 37% identity with TGF- $\beta$ 2; 36% identity with TGF- $\beta$ 1; 25% identity with Mullerian Inhibiting Substance (MIS), a testicular glycoprotein that causes regression of the Mullerian duct during development of the male embryo; 25% identity with inhibin  $\alpha$ ; 38% identity with inhibin  $\beta_B$ ; 45% identity with inhibin  $\beta_A$ ; 56% identity with Vgl, a *Xenopus* factor which may be involved in mesoderm induction in early embryogenesis (Weeks and Melton, *Cell* 51:861-867 (1987)); and 57% identity with Dpp the product of the *Drosophila* decapentaplegic locus which is required for dorsal-ventral specification in early embryogenesis and is involved in various other developmental processes at later stages of development [Padgett, et al., *Nature* 325:81-84 (1987)].

#### C. Human BMP-6 Proteins

Six clones which hybridize to the second probe described in Example V.A. more strongly than to the third are picked and transformed into plasmids. Restriction mapping, Southern blot analysis, and DNA sequence analysis of these plasmids indicate that there are two classes of clones. Clones U2-7 and U2-10 contain human BMP-6 coding sequence based on their stronger hybridization to the second probe and closer DNA homology to the bovine BMP-6 sequence of Table II than the other 4 clones. DNA sequence data derived from these clones indicates that they encode a partial polypeptide of 132 amino acids comprising the carboxy-terminus of the human BMP-6 protein. U2-7 was deposited with the American Type Culture Collection (ATCC), Rockville, Maryland on June 23, 1989 under accession number 68021 under the provisions of the Budapest Treaty.

A primer extended cDNA library is made from U-2 OS mRNA using the oligonucleotide GGAATCCAAGGCAGAATGTG, the sequence being based on the 3' untranslated sequence of the human BMP-6 derived from the clone U2-10. This library is screened with an oligonucleotide of the sequence CAGAGTCGTAATCGC, derived from the BMP-6 coding sequence of U2-7 and U2-10. Hybridization is in standard hybridization buffer (SHB) at 42 degrees centigrade, with wash conditions of 42 degrees centigrade, 5X SSC, 0.1% SDS. Positively hybridizing clones are isolated. The DNA insert of one of these clones, PEH6-2, indicates that it extends further in a 5' direction than either U2-7 or U2-10. A primer extended cDNA library constructed from U-20S mRNA as above is screened with an oligonucleotide of the sequence GCCTCTCCCCCTCCGACGCCCCGTCTCGT, derived from the



sequ nce near the 5' end of PEH6-2. Hybridization is at 65 degrees centigrade in SHB, with washing at 65 degrees centigrade in 2X SSC, 0.1% SDS. Positively hybridizing recombinants are isolated and analyzed by restriction mapping and DNA sequence analysis.

The 5' sequence of the insert of one of the positively hybridizing recombinants, PE5834#7, is used to design an oligonucleotide of the sequence CTGCTGCTCCTCCTGCTGCCGGAGCGC. A random primed cDNA library [synthesized as for an oligo (dT) primed library except that (dN)<sub>6</sub> is used as the primer] is screened with this oligonucleotide by hybridization at 65 degrees centigrade in SHB with washing at 65 degrees centigrade in 1X SSC, 0.1% SDS. A positively hybridizing clone, RP10, is identified, isolated, and the DNA sequence sequence from the 5' end of its insert is determined. This sequence is used to design an oligonucleotide of the sequence TCGGGCTTCCTGTACCGGCGGCTCAAGACGCAGGAGAAGCGGGAGATGCA. A human placenta cDNA library (Stratagene catalog #936203) is screened with this oligonucleotide by hybridization in SHB at 65 degrees centigrade, and washing at 65 degrees centigrade with 0.2 X SSC, 0.1% SDS. A positively hybridizing recombinant designated BMP6C35 is isolated. DNA sequence analysis of the insert of this recombinant indicates that it encodes the complete human BMP-6 protein. BMP6C35 was deposited with the American Type Culture Collection, 12301 Parklawn Drive, Rockville, Maryland USA on March 1, 1990 under Accession Number 68245 under the provisions of the Budapest Treaty.

The DNA and derived amino acid sequence of the

majority of the insert of BMP6C35 is given in Table IV. This DNA sequence contains an open reading frame of 1539 base pairs which encodes the 513 amino acid human BMP-6 protein precursor. The presumed initiator methionine codon is preceded by a 5'untranslated sequence of 159 base pairs with stop codons in all three reading frames. The stop codon at nucleotides 1699-1701 is followed by at least 1222 base pairs of 3'untranslated sequence. It is noted that U2-7 has a C residue at the position corresponding to the T residue at position 1221 of BMP6C35; U2-7 also has a C residue at the position corresponding to the G residue at position 1253 of BMP6C35. These do not cause amino acid differences in the encoded proteins, and presumably represent allelic variations.

The oligonucleotide TCGGGCTTCCTGTACCGGCGGCTCAAGACGCAGGAGAAGCGGGAGATGCA is used to screen a human genomic library (Toole et al supra), by hybridizing nitrocellulose replicas of  $1 \times 10^6$  recombinants with the oligonucleotide in SHB at 65 degrees centigrade, and washing at 65 degrees centigrade with 0.2 X SSC, 0.1% SDS. Positively hybridizing clones are purified. The oligonucleotide hybridizing region is localized to an approximately 1.5 kb Pst I fragment. DNA sequence analysis of this fragment confirms the 5' sequence indicated in Table IV.

The first underlined portion of the sequence in Table IV from amino acid #388 to #396, Ser-Thr-Gln-Ser-Gln-Asp-Val-Ala-Arg, corresponds to the similar sequence Ser-Thr-Pro-Alg-Gln-Asp-Val-Ser-Arg of the bovine sequence described above and set forth in Table II. The second underlined sequence

in Table IV from amino acid #415 through #421 His-Glu-Leu-Tyr-Val-Ser-Phe, corresponds to the tryptic fragment identified above from which the oligonucleotide probes are designed. The tryptic sequence His-Glu-Leu-Tyr-Val-Ser-Phe-(Ser) is noted to be similar to a sequence found in other BMP proteins for example the sequence His-Pro-Leu-Tyr-Val-Asp-Phe-Ser found in the bovine and human cartilage/bone protein BMP-2 sequence as described in Publication WO 88/00205. BMP-6 therefore represents a new member of the BMP subfamily of TGF- $\beta$  like molecules which includes the molecules BMP-2, BMP-3, BMP-4 described in Publications WO 88/00205 and WO 89/10409, as well as BMP-5 and BMP-7 described herein.

Based on knowledge of other BMP proteins, as well as other proteins in the TGF- $\beta$  family, BMP-6 is predicted to be synthesized as a precursor molecule and the precursor polypeptide would be cleaved between amino acid #381 and amino acid #382 yielding a 132 amino acid mature polypeptide with a calculated molecular weight of approximately 15Kd. The mature form of BMP-6 contains three potential N-linked glycosylation sites per polypeptide chain as does BMP-5.

The processing of BMP-6 into the mature form is expected to involve dimerization and removal of the N-terminal region in a manner analogous to the processing of the related protein TGF- $\beta$  [L.E. Gentry, et al., (1988); R. Darnyck, et al., (1985) supra]. It is contemplated that the active BMP-6 protein molecule is a dimer. It is further contemplated that the mature active species of BMP-5 comprises protein molecule is a homodimer comprised of two polypeptide subunits each subunit

comprising amino acid #382 - #513 as set forth in Table IV. Further active species of BMP-5 are contemplated such as proprotein dimers or a proprotein subunit and a mature subunit. Additional active BMP-5 proteins may comprise amino acid #388 - #513 thereby including the tryptic fragments found in the purified bovine material. Another BMP-5 protein of the invention comprises amino acid #412 - #513 thereby including the first conserved cystine residue.

5

10

TABLE IV

10	20	30	40	50
CGACCATGAG	AGATAAGGAC	TGAGGGCCAG	GAAGGGGAAG	CGAGCCCCGCC
60	70	80	90	100
GAGAGGTGGC	GGGGACTGCT	CACGCCAAGG	GCCACAGCGG	CCGCGCTCCG
110	120	130	140	150
GCCTCGCTCC	GCCGCTCCAC	GCCTCGCGGG	ATCCGCGGGG	GCAGCCCCGGC
159	168	177	186	195
CGGGCGGGG	ATG CCG GGG CTG GGG CGG AGG GCG CAG TGG CTG TGC			
	MET Pro Gly Leu Gly Arg Arg Ala Gln Trp Leu Cys			
(1)				
204	213	222	231	240
TGG TGG TGG GGG CTG CTG TGC AGC TGC TGC GGG CCC CCG CCG CTG				
Trp Trp Trp Gly Leu Leu Cys Ser Cys Cys Gly Pro Pro Pro Leu				
249	258	267	276	285
CGG CCG CCC TTG CCC GCT GCC GCG GCC GCC GCC GCC GGG GGG CAG				
Arg Pro Pro Leu Pro Ala Ala Ala Ala Ala Ala Ala Gly Gly Gln				
294	303	312	321	330
CTG CTG GGG GAC GGC GGG AGC CCC GGC CGC ACG GAG CAG CCG CCG				
Leu Leu Gly Asp Gly Gly Ser Pro Gly Arg Thr Glu Gln Pro Pro				
339	348	357	366	375
CCG TCG CCG CAG TCC TCC TCG GGC TTC CTG TAC CGG CGG CTC AAG				
Pro Ser Pro Gln Ser Ser Ser Gly Phe Leu Tyr Arg Arg Leu Lys				
384	393	402	411	420
ACG CAG GAG AAG CGG GAG ATG CAG AAG GAG ATC TTG TCG GTG CTG				
Thr Gln Glu Lys Arg Glu MET Gln Lys Glu Ile Leu Ser Val Leu				
429	438	447	456	465
GGG CTC CCG CAC CGG CCC CGG CCC CTG CAC GGC CTC CAA CAG CCG				
Gly Leu Pro His Arg Pro Arg Pro Leu His Gly Leu Gln Gln Pro				

Table IV  
(page 2 of 6)

474	483	492	501	510
CAG CCC CCG GCG CTC CGG CAG CAG GAG GAG CAG CAG CAG CAG CAG				
Gln Pro Pro Ala Leu Arg Gln Gln Glu Glu Gln Gln Gln Gln Gln				
519	528	537	546	555
CAG CTG CCT CGC GGA GAG CCC CCT CCC GGG CGA CTG AAG TCC GCG				
Gln Leu Pro Arg Gly Glu Pro Pro Pro Gly Arg Leu Lys Ser Ala				
564	573	582	591	600
CCC CTC TTC ATG CTG GAT CTG TAC AAC GCC CTG TCC GCC GAC AAC				
Pro Leu Phe MET Leu Asp Leu Tyr Asn Ala Leu Ser Ala Asp Asn				
609	618	627	636	645
GAC GAG GAC GGG GCG TCG GAG GGG GAG AGG CAG CAG TCC TGG CCC				
Asp Glu Asp Gly Ala Ser Glu Gly Glu Arg Gln Gln Ser Trp Pro				
654	663	672	681	690
CAC GAA GCA GCC AGC TCG TCC CAG CGT CGG CAG CCG CCC CCG GGC				
His Glu Ala Ala Ser Ser Ser Gln Arg Arg Gln Pro Pro Gly Ser				
699	708	717	726	735
GCC GCG CAC CCG CTC AAC CGC AAG AGC CTT CTG GCC CCC GGA TCT				
Pro Pro Gly Ala Ala His Pro Leu Asn Arg Lys Ser Leu Leu Ala				
744	753	762	771	780
GGC AGC GGC GGC GCG TCC CCA CTG ACC AGC GCG CAG GAC AGC GCC				
Gly Ser Gly Gly Ala Ser Pro Leu Thr Ser Ala Gln Asp Ser Ala				
789	798	807	816	825
TTC CTC AAC GAC GCG GAC ATG GTC ATG AGC TTT GTG AAC CTG GTG				
Phe Leu Asn Asp Ala Asp MET Val MET Ser Phe Val Asn Leu Val				
834	843	852	861	870
GAG TAC GAC AAG GAG TTC TCC CCT CGT CAG CGA CAC CAC AAA GAG				
Glu Tyr Asp Lys Glu Phe Ser Pro Arg Gln Arg His His Lys Glu				
879	888	897	906	915
TTC AAG TTC AAC TTA TCC CAG ATT CCT GAG GGT GAG GTG GTG ACG				
Phe Lys Phe Asn Leu Ser Gln Ile Pro Glu Gly Glu Val Val Thr				

Table IV  
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924	933	942	951	960
GCT GCA GAA TTC CGC ATC TAC AAG GAC TGT GTT ATG GGG AGT TTT				
Ph Arg Ile Tyr Lys Asp Cys Val MET Ala Ala Glu Gly Ser Phe				
969	978	987	996	1005
AAA AAC CAA ACT TTT CTT ATC AGC ATT TAT CAA GTC TTA CAG GAG				
Lys Asn Gln Thr Phe Leu Ile Ser Ile Tyr Gln Val Leu Gln Glu				
1014	1023	1032	1041	1050
CAT CAG CAC AGA GAC TCT GAC CTG TTT TTG TTG GAC ACC CGT GTA				
His Gln His Arg Asp Ser Asp Leu Phe Leu Leu Asp Thr Arg Val				
1059	1068	1077	1086	1095
GTA TGG GCC TCA GAA GAA GGC TGG CTG GAA TTT GAC ATC ACG GCC				
Val Trp Ala Ser Glu Glu Gly Trp Leu Glu Phe Asp Ile Thr Ala				
1104	1113	1122	1131	1140
ACT AGC AAT CTG TGG GTT GTG ACT CCA CAG CAT AAC ATG GGG CTT				
Thr Ser Asn Leu Trp Val Val Thr Pro Gln His Asn MET Gly Leu				
1149	1158	1167	1176	1185
CAG CTG AGC GTG GTG ACA AGG GAT GGA GTC CAC GTC CAC CCC CGA				
Gln Leu Ser Val Val Thr Arg Asp Gly Val His Val His Pro Arg				
1194	1203	1212	1221	1230
GCC GCA GGC CTG GTG GGC AGA GAC GGC CCT TAC GAT AAG CAG CCC				
Ala Ala Gly Leu Val Gly Arg Asp Gly Pro Tyr Asp Lys Gln Pro				
1239	1248	1257	1266	1275
TTC ATG GTG GCT TTC TTC AAA GTG AGT GAG GTC CAC GTG CGC ACC				
Phe MET Val Ala Phe Phe Lys Val Ser Glu Val His Val Arg Thr				
1284	1293	1302	1311	1320
ACC AGG TCA GCC TCC AGC CGG CGC CGA CAA CAG AGT CGT AAT CGC				
Thr Arg Ser Ala Ser Ser Arg Arg Arg Gln Gln Ser Arg Asn Arg				
		(382)		
1329	1338	1347	1356	1365
TCT ACC CAG TCC CAG GAC GTG GCG CGG GTC TCC AGT GCT TCA GAT				
Ser Thr Gln Ser Gln Asp Val Ala Arg Val Ser Ser Ala Ser Asp				
(388)				

Table IV  
(page 4 f 6)

1374	1383	1392	1401	1410
TAC AAC AGC AGT GAA TTG AAA ACA GCC TGC AGG AAG CAT GAG CTG				
Tyr Asn Ser Ser Glu Leu Lys Thr Ala Cys Arg Lys <u>His Glu Leu</u>				
		(412)		
1419	1428	1437	1446	1455
TAT GTG AGT TTC CAA GAC CTG GGA TGG CAG GAC TGG ATC ATT GCA				
<u>Tyr Val Ser Phe</u> Gln Asp Leu Gly Trp Gln Asp Trp Ile Ile Ala				
1464	1473	1482	1491	1500
CCC AAG GGC TAT GCT GCC AAT TAC TGT GAT GGA GAA TGC TCC TTC				
Pro Lys Gly Tyr Ala Ala Asn Tyr Cys Asp Gly Glu Cys Ser Phe				
1509	1518	1527	1536	1545
CCA CTC AAC GCA CAC ATG AAT GCA ACC AAC CAC GCG ATT GTG CAG				
Pro Leu Asn Ala His MET Asn Ala Thr Asn His Ala Ile Val Gln				
1554	1563	1572	1581	1590
ACC TTG GTT CAC CTT ATG AAC CCC GAG TAT GTC CCC AAA CCG TGC				
Thr Leu Val His Leu MET Asn Pro Glu Tyr Val Pro Lys Pro Cys				
1599	1608	1617	1626	1635
TGT GCG CCA ACT AAG CTA AAT GCC ATC TCG GTT CTT TAC TTT GAT				
Cys Ala Pro Thr Lys Leu Asn Ala Ile Ser Val Leu Tyr Phe Asp				
1644	1653	1662	1671	1680
GAC AAC TCC AAT GTC ATT CTG AAA AAA TAC AGG AAT ATG GTT GTA				
Asp Asn Ser Asn Val Ile Leu Lys Lys Tyr Arg Asn MET Val Val				
1689	1698	1708	1718	1728
AGA GCT TGT GGA TGC CAC TAACTCGAAA CCAGATGCTG GGGACACACA				
Arg Ala Cys Gly Cys His				
(513)				
1738	1748	1758	1768	1778
TTCTGCCTTG GATTCCCTAGA TTACATCTGC CTTAAAAAAA CACGGAAGCA				
1788	1798	1808	1818	1828
CAGTTGGAGG TGGGACGATG AGACTTTGAA ACTATCTCAT GCCAGTGCCT				
1838	1848	1858	1868	1878



Table IV  
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TATTACCCAG GAAGATTTTA AAGGACCTCA TTAATAATTT GCTCACTTGG

1888 1898 1908 1918 1928  
TAAATGACGT GAGTAGTTGT TGGTCTGTAG CAAGCTGAGT TTGGATGTCT

1938 1948 1958 1968 1978  
GTAGCATAAG GTCTGGTAAC TGCAGAAACA TAACCGTGAA GCTCTTCCTA

1988 1998 2008 2018 2028  
CCCTCCTCCC CCAAAAACCC ACCAAAATTA GTTTGTAGCTG TAGATCAAGC

2038 2048 2058 2068 2078  
TATTTGGGGT GTTTGTTAGT AAATAGGGAA AATAATCTCA AAGGAGTTAA

2088 2098 2108 2118 2128  
ATGTATTCTT GGCTAAAGGA TCAGCTGGTT CAGTACTGTC TATCAAAGGT

2138 2148 2158 2168 2178  
AGATTTTACA GAGAACAGAA ATCGGGGAAG TGGGGGGAAC GCCTCTGTTC

2188 2198 2208 2218 2228  
AGTTCATTCC CAGAAGTCCA CAGGACGCAC AGCCCAGGCC ACAGCCAGGG

2238 2248 2258 2268 2278  
CTCCACGGGG CGCCCTTGTC TCAGTCATTG CTGTTGTATG TTCGTGCTGG

2288 2298 2308 2318 2328  
AGTTTGTGTTG GTGTGAAAAT ACACTTATTT CAGCCAAAAC ATACCATTTC

2338 2348 2358 2368 2378  
TACACCTCAA TCCTCCATTT GCTGTACTCT TTGCTAGTAC CAAAAGTAGA

2388 2398 2408 2418 2428  
CTGATTACAC TGAGGTGAGG CTACAAGGGG TGTGTAACCG TGTAACACGT

2438 2448 2458 2468 2478  
GAAGGCAGTG CTCACCTCTT CTTTACCAGA ACGGTTCTTT GACCAGCACA

Table IV  
(page 6 of 6)

2488	2498	2508	2518	2528
TTAACTTCTG	GACTGCCGGC	TCTAGTACCT	TTTCAGTAAA	GTGGTTCTCT
2538	2548	2558	2568	2578
GCCTTTTTTAC	TATACAGCAT	ACCACGCCAC	AGGGTTAGAA	CCAACGAAGA
2588	2598	2608	2618	2628
AAATAAAATG	AGGGTGCCCA	GCTTATAAGA	ATGGTGTTAG	GGGGATGAGC
2638	2648	2658	2668	2678
ATGCTGTTTA	TGAACGGAAA	TCATGATTTC	CCTGTAGAAA	GTGAGGCTCA
2688	2698	2708	2718	2728
GATTAAATTT	TAGAATATTT	TCTAAATGTC	TTTTTCACAA	TCATGTGACT
2738	2748	2758	2768	2778
GGGAAGGCAA	TTTCATACTA	AACTGATTAA	ATAATACATT	TATAATCTAC
2788	2798	2808	2818	2828
AACTGTTTGC	ACTTACAGCT	TTTTTTGTAA	ATATAAACTA	TAATTTATTG
2838	2848	2858	2868	2878
TCTATTTTAT	ATCTGTTTTG	CTGTGGCGTT	GGGGGGGGGG	CCGGGCTTTT
2888	2898	2908	2918	
GGGGGGGGGG	GTTTGTTTGG	GGGGTGTCGT	GGTGTGGGCG	GGCGG

Comparison of the sequence of murine Vgr-1 [Lyons, et al., PNAS 86:4554 (1989)] to human BMP-6 reveals a degree of amino acid sequence identity greater than 92%. The murine Vgr-1 is likely the murine homologue of BMP-6. Human BMP-6 shares homology with other BMP molecules as well as other members of the TGF- $\beta$  superfamily of molecules. The cysteine-rich carboxy-terminal 102 amino acid residues of human BMP-6 shares the following homologies with BMP proteins disclosed herein and in Publications WO 88/00205 and WO 89/10409: 61% identity with BMP-2; 44% identity with BMP-3, 60% identity with BMP-4; 91% identity with BMP-5; and 87% identity with BMP-7. Human BMP-6 further shares the following homologies: 41% identity with TGF- $\beta$ 3; 39% identity with TGF- $\beta$ 2; 37% identity with TGF- $\beta$ 1; 26% identity with Mullerian Inhibiting Substance (MIS), a testicular glycoprotein that causes regression of the Mullerian duct during development of the male embryo; 25% identity with inhibin  $\alpha$ ; 43% identity with inhibin  $\beta_B$ ; 49% identity with inhibin  $\beta_A$ ; 58% identity with Vgl, a *Xenopus* factor which may be involved in mesoderm induction in early embryogenesis (Weeks and Melton, (1987) Supra); and 59% identity with Dpp the product of the *Drosophila* decapentaplegic locus which is required for dorsal-ventral specification in early embryogenesis and is involved in various other developmental processes at later stages of development [Padgett, et al., (1987) supra].

#### D. Human BMP-7 Proteins

The other four clones of Example V.C. above which appear to represent a second class of clones

5 encode a novel polypeptide which we designate as  
BMP-7. One of these clones, U2-5, was deposited  
with the ATCC on June 22, 1989 under accession  
number ATCC 68020 under the provisions of the  
10 Budapest Treaty. This clone was determined not to  
contain the entire coding sequence for BMP-7. An  
oligo of the sequence GCGAGCAATGGAGGATCCAG (designed  
on the basis of the 3' noncoding sequence of U2-5)  
was used to make a primer-extended cDNA library  
15 from U-2 OS mRNA (Toole, et al.). 500,000  
recombinants of this library were screened with the  
oligonucleotide GATCTCGCGCTGCAT (designed on the  
basis of the BMP-7 coding sequence) by  
hybridization in SHB at 42° and washing in 5X SSC,  
20 0.1% SDS at 42°. Several hybridizing clones were  
obtained. DNA sequence analysis and derived amino  
acid sequence of one of these clones, PEH7-9, is  
given in Table V. PEH7-9 was deposited with the  
American Type Culture Collection (ATCC), Rockville,  
Maryland on November 17, 1989 under accession  
number ATCC 68182 under the provisions of the  
Budapest Treaty. PEH7-9 contains an insert of 1448  
base pairs. This clone, PEH7-9, is expected to  
25 contain all of the nucleotide sequence necessary to  
encode BMP-7 proteins. The cDNA sequence of Table  
V contains an open reading frame of 1292 base  
pairs, encoding a protein of 431 amino acids,  
preceded by a 5' untranslated region of 96 base  
pairs with stop codons in all frames, and contains  
30 a 3' untranslated region of 60 base pairs following  
the in frame stop codon TAG.

This protein of 431 amino acids has a  
molecular weight of 49,000 daltons as predicted by  
its amino acid sequence and is contemplated to  
35 represent the primary translation product. Based

on knowledge of other BMP proteins as well as other proteins within the TGF- $\beta$  family, it is predicted that the precursor polypeptide would be cleaved between amino acid #299 and #300, yielding a 132 amino acid mature peptide.

It is contemplated that processing of BMP-7 to the mature form involves dimerization of the proprotein and removal of the N-terminal region in a manner analogous to the processing of the related protein TGF- $\beta$  [L.E. Gentry, et al., (1988) Supra and; R. Dernyck, et al., (1985) Supra]. It is contemplated therefore that the mature active species of BMP-7 comprises a homodimer of 2 polypeptide subunits each subunit comprising amino acid #300 - #431 as shown in Table V with a calculated weight of 15,000 daltons. Other active BMP-7 species are contemplated, for example, protein dimers or proprotein subunits linked to mature subunits. Additional active species may comprise amino acids #309 - #431 of Table V such species including the tryptic sequences found in the purified bovine material. Also contemplated are BMP-7 proteins comprising amino acids #330-#431 thereby including the first conserved cysteine residue.

The underlined sequence of Table V from amino acid #309 - #314 Asn-Gln-Glu-Ala-Leu-Arg is the same sequence as that of tryptic fragment #5 found in the 28,000 - 30,000 dalton purified bone preparation as described in the "BMP" Publications WO 88/00205 and WO 89/10409 mentioned above. The underlined sequence of Table V from amino acid #333-#339 His-Glu-Leu-Tyr-Val-Ser-Phe corresponds to the tryptic fragment identified in the bovine bone preparation described above from which the

ligonucleotide probes ar designed.

TABLE V

10	20	30	40	50
GTGACCGAGC	GGGCGGAAG	GGGCGTGGC	CCCTCTGCA	CCTGGGGGGG
60	70	80	90	99
TGCGGGGCGG	GAGCGCGAG	CCCGGGTAC	GCGTAGAGC	GGGCGG ATG
				MET
				(1)
108	117	126	135	144
CAC GTG CGC TCA CTG CGA GCT GCG GCG CCG CAC AGC TTC GTG GCG				
His Val Arg Ser Leu Arg Ala Ala Ala Pro His Ser Phe Val Ala				
153	162	171	180	189
CTC TGG GCA CCC CTG TTC CTG CTG CGC TOC GCG CTG GCG GAC TTC				
Leu Trp Ala Pro Leu Phe Leu Leu Arg Ser Ala Leu Ala Asp Phe				
198	207	216	225	234
AGC CTG GAC AAC GAG GTG CAC TOG AGC TTC ATC CAC CGG CGC CTC				
Ser Leu Asp Asn Glu Val His Ser Ser Phe Ile His Arg Arg Leu				
243	252	261	270	279
CGC AGC CAG GAG CGG CGG GAG ATG CAG CGC GAG ATC CTC TOC ATT				
Arg Ser Gln Glu Arg Arg Glu MET Gln Arg Glu Ile Leu Ser Ile				
288	297	306	315	324
TTG GGC TTG CCC CAC CGC CGG CGC CGG CAC CTC CAG GGC AAG CAC				
Leu Gly Leu Pro His Arg Pro Arg Pro His Leu Gln Gly Lys His				
333	342	351	360	369
AAC TOG GCA CCC ATG TTC ATG CTG GAC CTG TAC AAC GCG ATG GCG				
Asn Ser Ala Pro MET Phe MET Leu Asp Leu Tyr Asn Ala MET Ala				
378	387	396	405	414
GTG GAG GAG GGC GGC GGG CCC GGC GGC CAG GGC TTC TOC TAC CCC				
Val Glu Glu Gly Gly Gly Pro Gly Gly Gln Gly Phe Ser Tyr Pro				
423	432	441	450	459
TAC AAG GCG GTC TTC AGT ACC CAG GGC CCC OCT CTG GCG AGC CTG				
Tyr Lys Ala Val Phe Ser Thr Gln Gly Pro Pro Leu Ala Ser Leu				
468	477	486	495	504
CAA GAT AGC CAT TTC CTC ACC GAC GCG GAC ATG GTC ATG AGC TTC				
Gln Asp Ser His Phe Leu Thr Asp Ala Asp MET Val MET Ser Phe				
513	522	531	540	549
GTC AAC CTC GTG GAA CAT GAC AAG GAA TTC TTC CAC OCA CGC TAC				
Val Asn Leu Val Glu His Asp Lys Glu Phe Phe His Pro Arg Tyr				

Table V  
(page 2 of 3)

558	567	576	585	594
CAC CAT CGA GAG TTC	OGG TTT GAT CTT	TOC AAG ATC CCA	GAA GGG	
His His Arg Glu Phe	Arg Phe Asp Leu	Ser Lys Ile Pro	Glu Gly	
603	612	621	630	639
GAA GCT GTC ACG GCA	GCC GAA TTC	OGG ATC TAC AAG	GAC TAC ATC	
Glu Ala Val Thr Ala	Ala Glu Phe Arg	Ile Tyr Lys Asp	Tyr Ile	
648	657	666	675	684
OGG GAA CGC TTC GAC	AAT GAG ACG TTC	OGG ATC AGC GTT	TAT CAG	
Arg Glu Arg Phe Asp	Asn Glu Thr Phe	Arg Ile Ser Val	Tyr Gln	
693	702	711	720	729
GTG CTC CAG GAG CAC	TTG GGC AGG GAA	TOG GAT CTC TTC	CTG CTC	
Val Leu Gln Glu His	Leu Gly Arg Glu	Ser Asp Leu Phe	Leu Leu	
738	747	756	765	774
GAC AGC CGT ACC CTC	TGG GGC TOG GAG	GAG GGC TGG CTG	GTG TTT	
Asp Ser Arg Thr Leu	Trp Ala Ser Glu	Glu Gly Trp Leu	Val Phe	
783	792	801	810	819
GAC ATC ACA GGC ACC	AGC AAC CAC TGG	GTG GTC AAT CCG	OGG CAC	
Asp Ile Thr Ala Thr	Ser Asn His Trp	Val Val Asn Pro	Arg His	
828	837	846	855	864
AAC CTG GGC CTG CAG	CTC TOG GTG GAG	ACG CTG GAT GGG	CAG AGC	
Asn Leu Gly Leu Gln	Leu Ser Val Glu	Thr Leu Asp Gly	Gln Ser	
873	882	891	900	909
ATC AAC CCC AAG TTG	GCG GGC CTG ATT	GGG OGG CAC GGG	CCC CAG	
Ile Asn Pro Lys Leu	Ala Gly Leu Ile	Gly Arg His Gly	Pro Gln	
918	927	936	945	954
AAC AAG CAG CCC TTC	ATG GTG GCT TTC	AAG GGC ACG GAG	GTC	
Asn Lys Gln Pro Phe	MET Val Ala Phe	Phe Lys Ala Thr	Glu Val	
963	972	981	990	999
CAC TTC CGC AGC ATC	OGG TOC ACG GGG	AGC AAA CAG OGC	AGC CAG	
His Phe Arg Ser Ile	Arg Ser Thr Gly	Ser Lys Gln Arg	Ser Gln	
1008	1017	1026	1035	1044
AAC CGC TOC AAG ACG	CCC AAG AAC CAG	GAA GGC CTG OGG	ATG GCC	
Asn Arg Ser Lys Thr	Pro Lys <u>Asn Gln Glu</u>	<u>Ala Leu Arg</u>	MET Ala	
1053	1062	1071	1080	1089
AAC GTG GCA GAG AAC	AGC AGC AGC GAC	CAG AGG CAG GGC	TGT AAG	
Asn Val Ala Glu Asn	Ser Ser Ser Asp	Gln Arg Gln Ala	Cys Lys	

(330)



Table V  
(page 3 of 3)

1098	1107	1116	1125	1134
AAG CAC GAG CTG TAT GTC AGC TTC CGA GAC CTG GGC TGG CAG GAC				
Lys His Glu Leu Tyr Val Ser Phe Arg Asp Leu Gly Trp Gln Asp				
1143	1152	1161	1170	1179
TGG ATC ATC GCG OCT GAA GGC TAC GGC GGC TAC TAC TGT GAG GGG				
Trp Ile Ile Ala Pro Glu Gly Tyr Ala Ala Tyr Tyr Cys Glu Gly				
1188	1197	1206	1215	1224
GAG TGT GGC TTC OCT CTG AAC TCC TAC ATG AAC GGC ACC AAC CAC				
Glu Cys Ala Phe Pro Leu Asn Ser Tyr MET Asn Ala Thr Asn His				
1233	1242	1251	1260	1269
GCC ATC GTG CAG ACG CTG GTC CAC TTC ATC AAC CCG GAA ACG GTG				
Ala Ile Val Gln Thr Leu Val His Phe Ile Asn Pro Ile Ser Val				
1278	1287	1296	1305	1314
CCC AAG CCC TGC TGT GCG CCC ACG CAG CTC AAT GCC ATC TCC GTC				
Pro Lys Pro Cys Cys Ala Pro Thr Gln Leu Asn Ala Ile Ser Val				
1323	1332	1341	1350	1359
CTC TAC TTC GAT GAC AGC TCC AAC GTC ATC CTG AAG AAA TAC AGA				
Leu Tyr Phe Asp Asp Ser Ser Asn Val Ile Leu Lys Lys Tyr Arg				
1368	1377	1386	1399	
AAC ATG GTG GTC CGG GGC TGT GGC TGC CAC TAGCTGCTCC				
Asn MET Val Val Arg Ala Cys Gly Cys His				
		(431)		
1409	1419	1429	1439	1448
GAGAATTCAG ACCCTTTGGG GCCAAGTTTT TCCTGGATCCT CCATTGCTC				

Like BMP-5 and BMP-6, human BMP-7 shares homology with other BMP molecules as well as other members of the TGF- $\beta$  superfamily of molecules. The cysteine-rich carboxy-terminal 102 amino acids residues of human BMP-7 shares the following homologies with BMP proteins herein and in Publications WO 88/00205 and WO 89/10409 described above: 60% identity with BMP-2; 43% identity with BMP-3, 58% identity with BMP-4, 87% identity with BMP-6; and 88% identity with BMP-5. Human BMP-7 further shares the following homologies: 40% identity with TGF- $\beta$ 3; 40% identity with TGF- $\beta$ 2; 36% identity with TGF- $\beta$ 1; 29% identity with Mullerian Inhibiting Substance (MIS), a testicular glycoprotein that causes regression of the Mullerian duct during development of the male embryo; 25% identity with inhibin- $\alpha$ ; 44% identity with inhibin- $\beta$ B; 45% identity with inhibin- $\beta$ A; 57% identity with Vg1, a Xenopus factor which may be involved in mesoderm induction in early embryogenesis [Weeks and Melton, (1987) Supra.]; and 58% identity with Dpp the product of the Drosophila decapentaplegic locus which is required for dorsal-ventral specification in early embryogenesis and is involved in various other developmental processes at later stages of development [Padgett, et al., (1987) Supra.].

The invention encompasses the genomic sequences of BMP-5, BMP-6 and BMP-7. To obtain these sequences the cDNA sequences described herein are utilized as probes to screen genomic libraries using techniques known to those skilled in the art.

The procedures described above and additional

5 methods known to those skilled in the art may be employed to isolate other related proteins of interest by utilizing the bovine or human proteins as a probe source. Such other proteins may find similar utility in, inter alia, fracture repair, wound healing and tissue repair.

#### EXAMPLE VI

##### Expression of BMP Proteins

10 In order to produce bovine, human or other mammalian BMP-5, BMP-6 or BMP-7 proteins of the invention, the DNA encoding it is transfected into an appropriate expression vector and introduced into mammalian cells or other preferred eukaryotic  
15 or prokaryotic hosts by conventional genetic engineering techniques. It is contemplated that the preferred expression system for biologically active recombinant human proteins of the invention will be stably transformed mammalian cells. For  
20 transient expression, the cell line of choice is SV40 transformed African green monkey kidney COS-1 or COS-7 which typically produce moderate amounts of the protein encoded within the plasmid for a period of 1-4 days. For stable high level  
25 expression of BMP-5, BMP-6 or BMP-7 the preferred cell line is Chinese hamster Ovary (CHO). It is therefore contemplated that the preferred mammalian cells will be CHO cells.

30 The transformed host cells are cultured and the BMP proteins of the invention expressed thereby are recovered, isolated and purified. Characterization of expressed proteins is carried out using standard techniques. For example,  
35 characterization may include pulse labeling with [<sup>35</sup>S] methionine or cysteine and analysis by

polyacrylamide electrophoresis. The recombinantly expressed BMP proteins are free of proteinaceous materials with which they are co-produced and with which they ordinarily are associated in nature, as well as from other contaminants, such as materials found in the culture media.

#### A. Vector Construction

As described above, numerous expression vectors known in the art may be utilized in the expression of BMP proteins of the invention. The vector utilized in the following examples is pMT21, a derivative of pMT<sub>2</sub>, though other vectors may be suitable in practice of the invention.

pMT<sub>2</sub> is derived from pMT2-VWF, which has been deposited with the American Type Culture Collection (ATCC), Rockville, MD (USA) under accession number ATCC 67122 under the provisions of the Budapest Treaty. EcoRI digestion excises the cDNA insert present in pMT-VWF, yielding pMT2 in linear form which can be ligated and used to transform E. Coli HB 101 or DH-5 to ampicillin resistance. Plasmid pMT2 DNA can be prepared by conventional methods.

pMT21 is then constructed using loopout/in mutagenesis [Morinaga, et al., Biotechnology 84:636 (1984)]. This removes bases 1075 to 1170 (inclusive). In addition it inserts the following sequence: 5' TCGA 3'. This sequence completes a new restriction site, XhoI. This plasmid now contains 3 unique cloning sites PstI, EcoRI, and XhoI.

In addition, pMT21 is digested with EcoRV and XhoI, treating the digested DNA with Klenow fragment of DNA polymerase I and ligating ClaI linkers (NEBio Labs, CATCGATG). This removes bases

2171 to 2420 starting from the HindIII site near the SV40 origin of replication and enhancer sequences of pMT2 and introduces a unique Cla I site, but leaves the adenovirus VAI gene intact.

5

#### B. BMP-5 Vector Construction

A derivative of the BMP-5 cDNA sequence set forth in Table III comprising the the nucleotide sequence from nucleotide #699 to #2070 is specifically amplified. The oligonucleotides CGACCTGCAGCCACCATGCATCTGACTGTA and TGCCTGCAGTTTAATATTAGTGGCAGC are utilized as primers to allow the amplification of nucleotide sequence #699 to #2070 of Table III from the insert of clone U2-16 described above in Example V. This procedure introduces the nucleotide sequence CGACCTGCAGCCACC immediately preceeding nucleotide #699 and the nucleotide sequence CTGCAGGCA immediately following nucleotide #2070. The addition of these sequences results in the creation of PstI restriction endonuclease recognition sites at both ends of the amplified DNA fragment. The resulting amplified DNA product of this procedure is digested with the restriction endonuclease PstI and subcloned into the PstI site of the pMT2 derivative pMT21 described above. The resulting clone is designated H5/5/pMT.

10

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The insert of H5/5/pMT is excised by PstI digestion and subcloned into the plasmid vector pSP65 at the PstI site resulting in BMP5/SP6. BMP5/SP6 and U2-16 are digested with the restriction endonucleases NsiI and NdeI to excise the portion of their inserts corresponding to nucleotides #704 to #1876 of Table III. The resulting 1173 nucleotide NsiI-NdeI fragment of

30

35

clone U2-16 is ligated into the NsiI-NdeI site of BMP5/SP6 from which the corresponding 1173 nucleotid NsiI-NdeI fragment had been removed. The resulting clone is designated BMP5mix/SP64.

5 Direct DNA sequence analysis of BMP5mix/SP64 is performed to confirm identity of the nucleotide sequences produced by the amplification to those set forth in Table III. The clone BMP5mix/SP64 is digested with the restriction endonuclease PstI  
10 resulting in the excision of an insert comprising the nucleotides #699 to #2070 of Table III and the additional sequences containing the PstI recognition sites as described above. The resulting 1382 nucleotide PstI fragment is  
15 subcloned into the PstI site of the pMT2 derivative pMT21. This clone is designated BMP5mix/pMT21#2.

#### C. BMP-6 Vector Construction

20 A derivative of the BMP-6 cDNA sequence set forth in Table IV comprising the nucleotide sequence from nucleotide #160 to #1706 is produced by a series of techniques known to those skilled in the art. The clone BMP6C35 described above in  
25 Example V is digested with the restriction endonucleases ApaI and TaqI, resulting in the excision of a 1476 nucleotide portion of the insert comprising nucleotide #231 to #1703 of the sequence set forth in Table IV. Synthetic olignuclotides  
30 with SalI restriction endonuclease site converters are designed to replace those nucleotides corresponding to #160 to #230 and #1704 to #1706 which are not contained in the 1476 ApaI-TaqI fragment of the BMP-6 cDNA sequence. Oligonucleotide/SalI converters conceived to  
35 r e p l a c e t h e m i s s i n g 5 '

(TCGACCCACCATGCCGGGGCTGGGGCGGAGGGCGCAGTGGCTGTG  
 CTGGTGGT GGGGGCTGTGCTGCAGCTGCTGCGGGCC and  
 CGCAGCAGCTGCACAGCAGCCCCCACCACCAGCACAGCCACTGCGCC  
 CTCCGCCCCAG CCCCAGCATGGTGGG) and 3' (TCGACTGGTTT  
 and CGAAACCAG) sequences are annealed to each other  
 independently. The annealed 5' and 3' converters  
 are then ligated to the 1476 nucleotide ApaI-TaqI  
 described above, creating a 1563 nucleotide  
 fragment comprising the nucleotide sequence from  
 #160 to #1706 of Table IV and the additional  
 sequences contrived to create Sall restriction  
 endonuclease sites at both ends. The resulting  
 1563 nucleotide fragment is subcloned into the Sall  
 site of pSP64. This clone is designated  
 BMP6/SP64#15.

DNA sequence analysis of BMP6/SP64#15 is  
 performed to confirm identity of the 5' and 3'  
 sequences replaced by the converters to the  
 sequence set forth in Table IV. The insert of  
 BMP6/SP64#15 is excised by digestion with the  
 restriction endonuclease Sall. The resulting 1563  
 nucleotide Sall fragment is subcloned into the XhoI  
 restriction endonuclease site of the pMT2  
 derivative pMT21 and designated herein as  
 BMP6/pMT21.

#### D. BMP-7 Vector Construction

A derivative of the BMP-7 sequence set forth  
 in Table V comprising the nucleotide sequence from  
 nucleotide #97 to #1402 is specifically amplified.  
 The oligonucleotides CAGGTCGACCCACCATGCACGTGCGCTCA  
 and TCTGTCGACCTCGGAGGAGCTAGTGGC are utilized as  
 primers to allow the amplification of nucleotide  
 sequence #97 to #1402 of Table V from the insert of  
 clone PEH7-9 described above. This procedure

generates the insertion of the nucleotide sequence CAGGTCGACCCACC immediately preceeding nucleotide #97 and the insertion of the nucleotide sequence GTCGACAGA immediately following nucleotide #1402. The addition of these sequences results in the creation of a SalI restriction endonuclease recognition site at each end of the amplified DNA fragment. The resulting amplified DNA product of this procedure is digested with the restriction endonuclease SalI and subcloned into the SalI site of the plasmid vector pSP64 resulting in BMP7/SP6#2.

The clones BMP7/SP6#2 and PEH7-9 are digested with the restriction endonucleases NcoI And StuI to excise the portion of their inserts corresponding to nucleotides #363 to #1081 of Table V. The resulting 719 nucleotide NcoI-StuI fragment of clone PEH7-9 is ligated into the NcoI-StuI site of BMP7/SP6#2 from which the corresponding 719 nucleotide fragment is removed. The resulting clone is designated BMP7mix/SP6.

Direct DNA sequence analysis of BMP7mix/SP6 confirmed identity of the 3' region to the nucleotide sequence from #1082 to #1402 of Table V, however the 5' region contained one nucleotide misincorporation.

Amplification of the nucleotide sequence (#97 to #1402 of Table V) utilizing PEH7-9 as a template is repeated as described above. The resulting amplified DNA product of this procedure is digested with the restriction endonucleases SalI and PstI. This digestion results in the excision of a 747 nucleotide fragment comprising nucleotide #97 to #833 of Table V plus the additional sequences of the 5' priming oligonucleotide used to create the



SalI restriction endonuclease recognition site described earlier. This 747 SalI-PstI fragment is subcloned into a SalI-PstI digested pSP65 vector resulting in 5'BMP7/SP65. DNA sequence analysis demonstrates that the insert of the 5'BMP7/SP65#1 comprises a sequence identical to nucleotide #97 to #362 of Table V.

The clones BMP7mix/SP6 and 5'BMP7/SP65 are digested with the restriction endonucleases SalI and NcoI. The resulting 3' NcoI-SalI fragment of BMP7mix/SP6 comprising nucleotides #363 to #1402 of Table V and 5' SalI-NcoI fragment of 5'BMP7/SP65 comprising nucleotides #97 to #362 of Table V are ligated together at the NcoI restriction sites to produce a 1317 nucleotide fragment comprising nucleotides #97 to #1402 of Table V plus the additional sequences derived from the 5' and 3' oligonucleotide primers which allows the creation of SalI restriction sites at both ends of this fragment. This 1317 nucleotide SalI fragment is ligated into the SalI site of the pMT2 derivative pMT2Cla-2. This clone is designated BMP7/pMT2.

The insert of BMP7/pMT2 is excised by digestion with the restriction endonuclease SalI. The resulting 1317 nucleotide SalI fragment is subcloned into the SalI restriction site of the vector pSP64. This clone is designated BMP7/SP64#2d. The insert of BMP7/SP64#2d is excised by digestion with SalI and the resulting SalI fragment comprising nucleotides #97 to #1402 of Table V is subcloned into the XhoI restriction endonuclease site of the pMT2 derivative pMT21 described above.

Example VII

### Transient COS Cell Expression

To obtain transient expression of BMP-5, BMP-6, and BMP-7 proteins one of the vectors containing the cDNA for BMP-5, BMP-6 or BMP-7, BMP5mix/pMT21#2, BMP6/pMT21#2, or BMP7/pMT21 respectively, are transfected into COS-1 cells using the electroporation method. Other suitable transfection methods include DEAE-dextran, and lipofection. Approximately 48 hours later, cells are analysed for expression of both intracellular and secreted BMP-5, BMP-6 or BMP-7 protein by metabolic labelling with [<sup>35</sup>S] methionine and polyacrylamide gel electrophoresis. Intracellular BMP is analyzed in cells which are treated with tunicamycin, an inhibitor of N-linked glycosylation. In tunicamycin-treated cells, the nonglycosylated primary translation product migrates as a homogeneous band of predictable size and is often easier to discern in polyacrylamide gels than the glycosylated form of the protein. In each case, intracellular protein in tunicamycin-treated cells is compared to a duplicate plate of transfected, but untreated COS-1 cells.

#### A. BMP-5 COS Expression

The results demonstrate that intracellular forms of BMP-5 of approximately 52 Kd and 57 Kd are made by COS cells. The 52 Kd protein is the size predicted by the primary sequence of the the BMP-5 cDNA clone. Following treatment of the cells with tunicamycin, only the 52 Kd form of BMP-5 is made, suggesting that the 57 Kd protein is a glycosylated derivative of the 52 Kd primary translation product. The 57 Kd protein is secreted into the conditioned medium and is apparently not

efficiently processed by COS-1 cells into the pro and mature peptides.

#### B. BMP-6 COS Expression

5 Intracellular BMP-6 exists as a doublet of approximately 61 Kd and 65 Kd in untreated COS-1 cells. In the presence of tunicamycin, only the 61 Kd protein is observed, indicating that the 65 Kd protein is the glycosylated derivative of the 61 Kd primary translation product. This is similar to the molecular weight predicted by the cDNA clone for BMP-6. In the absence of tunicamycin, the predominant protein secreted from COS-1 cells is the 65 Kd glycosylated, unprocessed clipped form of BMP-6. There are also peptides of 46 Kd and 20 Kd present at lower abundance than the 65 Kd that likely represent the processed pro and mature peptides, respectively.

#### C. BMP-7 COS Expression

20 Intracellular BMP-7 protein in tunicamycin-treated COS-1 cells is detected as a doublet of 44 Kd and 46 Kd. In the absence of tunicamycin, proteins of 46 Kd and perhaps 48 Kd are synthesized. These likely represent glycosylated derivatives of the BMP-7 primary translation products. The 48 Kd protein is the major BMP species secreted from COS-1 cells, again suggesting inefficient cleavage of BMP-7 at the propeptide dibasic cleavage site.

#### Example VIII

##### CHO Cell Expression

35 DHFR deficient CHO cells (DUKX B11) are transfected by electroporation with one of the BMP-5, BMP-6 or BMP-7 expression vectors described

above, and selected for expression of DHFR by growth in nucleoside-free media. Other methods of transfection, including but not limited to  $\text{CaPO}_4$  precipitation, protoplast fusion, microinjection, and lipofection, may also be employed. In order to obtain higher levels of expression more expediently, cells may be selected in nucleoside-free media supplemented with 5 nM, 20 nM or 100 nM MTX. Since the DHFR selectable marker is physically linked to the BMP cDNA as the second gene of a bicistronic coding region, cells which express DHFR should also express the BMP encoded within the upstream cistron. Either single clones, or pools of combined clones, are expanded and analyzed for expression of BMP protein. Cells are selected in stepwise increasing concentrations of MTX (5 nM, 20 nM, 100 nM, 500 nM, 2  $\mu\text{M}$ , 10  $\mu\text{M}$ , and 100  $\mu\text{M}$ ) in order to obtain cell lines which contain multiple copies of the expression vector DNA by virtue of gene amplification, and hence secrete large amounts of BMP protein.

Using standard techniques cell lines are screened for expression of BMP RNA, protein or activity, and high expressing cell lines are cloned or recloned at the appropriate level of selection to obtain a more homogeneous population of cells. The resultant cell line is then further characterized for BMP DNA sequences, and expression of BMP RNA and protein. Suitable cell lines can then be used for producing recombinant BMP protein.

#### A. CHO Expression of BMP-5

The BMP-5 vector BMP5mix/pMT21#2 described above is transfected into CHO cells by electroporation, and cells are selected for

expression of DHFR. Clonal cell lines are obtained from individual colonies selected stepwise for resistance to MTX, and analyzed for secretion of BMP-5 proteins. In some cases cell lines may be maintained as pools and cloned at later stages of MTX selection.

As described in Example V.B. the cDNA for BMP-5 encodes for a protein of approximately 52 Kd. Following processing within the cell that includes, but may not be limited to, propeptide cleavage, glycosylation, and dimer or multimer formation, multiple BMP-5 peptides are produced. There are at least 4 candidate peptides for processed forms of the BMP-5 protein discernable following SDS PAGE under reducing conditions; a 65 Kd peptide, a 35 Kd peptide, and a doublet of approximately 22 Kd molecular weight. Other less abundant BMP-5 peptides may also be present. By comparison to the processing of other related BMP molecules and the related protein TGF-beta, the 65 Kd protein likely represents unprocessed BMP-5, the 35 Kd species represents the propeptide, and the 22 Kd doublet represents the mature peptide.

Material from a BMP-5 cell line is analyzed in a 2-dimensional gel system. In the first dimension, proteins are electrophoresed under nonreducing conditions. The material is then reduced, and electrophoresed in a second polyacrylamide gel. Proteins that form disulfide-bonded dimers or multimers will run below a diagonal across the second reduced gel. Results from analysis of BMP-5 protein indicates that a significant amount of the mature BMP-5 peptides can form homodimers of approximately 30-35 Kd that reduce to the 22 Kd doublet observed in on

dimensional reduced gels. A fraction of the mature peptides are apparently in a disulfide-bonded complex with the pro peptide. The amount of this complex is minor relative to the mature homodimer. In addition, some of the unprocessed protein can apparently form homodimers or homomultimers.

#### B. CHO Expression of BMP-6

The BMP-6 expression vector BMP6/pMT21 described above is transferred into CHO cells and selected for stable transformants via DHFR expression in a manner as described above in part A with relation to BMP-5. The mature active species of BMP-6 is contemplated to comprise amino acid #382 - #513 of Table IV. It is contemplated that secreted BMP-6 protein will be processed in a manner similar to that described above for BMP-5, other related BMP molecules and analogous to the processing of the related protein TGF- $\beta$  [Gentry, et al.; Dernyck, et al., Supra.].

#### C. CHO Expression of BMP-7

The BMP-7 expression vector BMP7/pMT21 described above is transfected into CHO cells and selected for stable transformants via DHFR expression in a manner as described above in relation to BMP-5. The mature active species of BMP-7 is contemplated to comprise amino acid #300-#431 of Table V. It is contemplated that secreted BMP-7 protein will be processed in a manner similar to that described above for BMP-5, other related BMP molecules and analogous to the processing of the related protein TGF- $\beta$  [Gentry, et al.; Dernyck, et al., Supra.].

## EXAMPLE IX

Biological Activity of Expressed BMP Proteins

To measure the biological activity of the expressed BMP-5, BMP-6 and BMP-7 proteins obtained in Example VII and VIII above, the BMP proteins are recovered from the culture media and purified by isolating the BMP proteins from other proteinaceous materials with which they are co-produced, as well as from other contaminants. The proteins may be partially purified on a Heparin Sepharose column and further purified using standard purification techniques known to those skilled in the art.

For instance, post transfection conditioned medium supernatant collected from the cultures is concentrated approximately 10 fold by ultrafiltration on a YM 10 membrane and then dialyzed against 20mM Tris, 0.15 M NaCl, pH 7.4 (starting buffer). This material is then applied to a Heparin Sepharose column in starting buffer. Unbound proteins are removed by a wash of starting buffer, and bound proteins, including proteins of the invention, are desorbed by a wash of 20 mM Tris, 2.0 M NaCl, pH 7.4. The proteins bound by the Heparin column are concentrated approximately 10-fold on, for example, a Centricon 10 and the salt reduced by diafiltration with, for example, 0.1% trifluoroacetic acid. The appropriate amount of the resultant solution is mixed with 20 mg of rat matrix and then assayed for in vivo bone and/or cartilage formation activity by the Rosen-modified Sampath - Reddi assay. A mock transfection supernatant fractionation is used as a control.

Further purification may be achieved by

preparativ NaDodSO<sub>4</sub>/PAGE [Laemmli, Nature 227:680-685 (1970)]. for instance, approximately 300 µg of protein is applied to a 1.5-mm-thick 12.5% gel: recovery is be estimated by adding L-[<sup>35</sup>S]methionine-labeled BMP protein purified over heparin-Sepharose as described above. Protein may be visualized by copper staining of an adjacent lane [Lee, et al., Anal. Biochem. 166:308-312 (1987)]. Appropriate bands are excised and extracted in 0.1% NaDodSO<sub>4</sub>/20 mM Tris, pH 8.0. The supernatant may be acidified with 10% CF<sub>3</sub>COOH to pH 3 and the proteins are desalted on 5.0 x 0.46 cm Vydac C<sub>4</sub> column (The Separations Group, Hesperia, CA) developed with a gradient of 0.1% CF<sub>3</sub>COOH to 90% acetonitrile/0.1% CF<sub>3</sub>COOH.

The implants containing rat matrix to which specific amounts of human BMP-5, BMP-6 or BMP-7 proteins of the invention have been added are removed from rats after approximately seven days and processed for histological evaluation. Representative sections from each implant are stained for the presence of new bone mineral with von Kossa and acid fuchsin, and for the presence of cartilage-specific matrix formation using toluidine blue. The types of cells present within the section, as well as the extent to which these cells display phenotype are evaluated and scored as described in Example III.

Levels of activity may also be tested for host cell extracts. Purification is accomplished in a similar manner as described above except that 6 M urea is included in all the buffers.

The foregoing descriptions detail presently preferred embodiments of the present invention. Numerous



modifications and variations in practice thereof are expected to occur to those skilled in the art upon consideration of these descriptions. Those modifications and variations are believed to be encompassed within the claims appended hereto.

What is claimed is:

1. A purified human BMP protein selected from the group consisting of:
  - (a) BMP-5 characterized by the amino acid sequence comprising amino acid #323 to #454 of Table III;
  - (b) BMP-6 characterized by the amino acid sequence comprising amino acid #382 to #513 of Table IV; and
  - (c) BMP-7 characterized by the amino acid sequence comprising amino acid #300 to #431 of Table V.
2. A purified human BMP protein selected from the group consisting of
  - (a) BMP-5 protein produced by the steps of
    - (i) culturing a cell transformed with a DNA sequence comprising nucleotide #1665 to #2060 of Table III or a sequence substantially homologous thereto; and
    - (ii) recovering, isolating and purifying from said culture medium a protein comprising amino acid #323 to #454 as shown in Table III or a sequence substantially homologous thereto;
  - (b) BMP-6 produced by the steps of
    - (i) culturing a cell transformed with a DNA sequence comprising nucleotide #1303 to #1698 of Table IV or a sequence substantially homologous thereto; and
    - (ii) recovering, isolating and purifying

from said culture medium a protein comprising amino acid #382 to #513 as shown in Table IV or a sequence substantially homologous thereto; and

- (c) BMP-7 protein produced by the steps of
  - (i) culturing a cell transformed with a DNA sequence comprising nucleotide #994 to #1389 of Table V or a sequence substantially homologous thereto; and
  - (ii) recovering, isolating and purifying from said culture medium a protein comprising the amino acid #300 to amino acid #431 as shown in Table V or a sequence substantially homologous thereto.
- 3. A purified human BMP protein selected from the group consisting of
  - (a) BMP-5 produced by the steps of
    - (i) culturing a cell transformed with a DNA sequence comprising nucleotide #699 to #2060 of Table III or a sequence substantially homologous thereto; and
    - (ii) recovering, isolating and purifying from said culture medium said BMP-5 protein;
  - (b) BMP-6 produced by the steps of
    - (i) culturing a cell transformed with a DNA sequence comprising nucleotide #160 to #1698 of Table IV or a sequence substantially homologous thereto; and

- (ii) recovering, isolating and purifying from said culture medium said BMP-6 protein; and
  - (c) BMP-7 produced by the steps of
    - (i) culturing a cell transformed with a DNA sequence comprising nucleotide #97 to #1389 of Table V or a sequence substantially homologous thereto; and
    - (ii) recovering, isolating and purifying from said culture medium said BMP-7 protein.
4. A purified BMP protein produced by the steps of:
- (a) culturing a cell transformed with a DNA sequence comprising a sequence which hybridizes to the DNA sequence selected from the DNA sequences of Table III comprising nucleotide #1665 - #2060, Table IV comprising nucleotide #1303-#1698 or Table V comprising nucleotide #994 - #1389 under stringent hybridization conditions; and
  - (b) recovering, isolating and purifying from said culture medium a protein characterized by the ability to induce cartilage and/or bone formation.
5. A protein of claim 1 further characterized by the ability to demonstrate the induction of cartilage and/or bone formation.
6. A protein of claim 2 further characterized by the ability to demonstrate the induction of

cartilage and/or bone formation.

7. A protein of claim 3 further characterized by the ability to demonstrate the induction of cartilage and/or bone formation.
8. A DNA sequence encoding a protein of claim 1.
9. A DNA sequence encoding a BMP protein said DNA sequence selected from the group consisting of
  - (a) a DNA sequence encoding BMP-5 comprising the nucleotide #1665 to #2060 of Table III and sequences which hybridize thereto under stringent hybridization conditions and encode a protein characterized by the ability to induce the formation of cartilage and/or bone;
  - (b) a DNA sequence encoding BMP-6 comprising nucleotide #1303 - #1698 of Table IV and sequences which hybridize thereto under stringent hybridization conditions and encode a protein characterized by the ability to induce the formation of cartilage and/or bone;
  - (c) a DNA sequence encoding BMP-7 comprising nucleotide #994 - #1389 of Table V and sequences which hybridize thereto under stringent hybridization conditions and encode a protein characterized by the ability to induce the formation of cartilage and/or bone;
10. A DNA sequence encoding a BMP protein selected from the group consisting of

- (a) a DNA sequence encoding BMP-5 comprising the nucleotide #669 to #2060 of Table III and sequences which hybridize thereto under stringent hybridization conditions and encode a protein characterized by the ability to induce the formation of cartilage and/or bone;
  - (b) a DNA sequence encoding BMP-6 comprising nucleotide #160 - #1698 of Table IV and sequences which hybridize thereto under stringent hybridization conditions and encode a protein characterized by the ability to induce the formation of cartilage and/or bone;
  - (c) a DNA sequence encoding BMP-7 comprising nucleotide #97 - #1389 of Table V and sequences which hybridize thereto under stringent hybridization conditions and encode a protein characterized by the ability to induce the formation of cartilage and/or bone;
- 11. A vector comprising a DNA sequence of claim 8 in operative association with an expression control sequence therefor.
  - 12. A vector comprising a DNA sequence of claim 9 in operative association with an expression control sequence therefor.
  - 13. A vector comprising a DNA sequence of claim 10 in operative association with an expression control sequence therefor.
  - 14. A host cell transformed with a vector of claim

- 11.
15. A host cell transformed with a vector of claim 12.
16. A host cell transformed with a vector of claim 13.
17. A method for producing a purified BMP protein said method comprising the steps of
  - (a) culturing in a suitable culture medium a transformed host cell of claim 14; and
  - (b) recovering, isolating and purifying said protein from said culture medium.
18. A method for producing a purified BMP protein said method comprising the steps of
  - (a) culturing in a suitable culture medium a transformed host cell of claim 15; and
  - (b) recovering, isolating and purifying said protein from said culture medium.
19. A method for producing a purified BMP protein said method comprising the steps of
  - (a) culturing in a suitable culture medium a transformed host cell of claim 16; and
  - (b) recovering, isolating and purifying said protein from said culture medium.
20. A pharmaceutical composition comprising an effective amount of a BMP-5, BMP-6 or BMP-7 protein in admixture with a pharmaceutically acceptable vehicle.
21. A pharmaceutical composition comprising an

effective amount of a protein of claim 1 in admixture with a pharmaceutically acceptable vehicle.

22. A pharmaceutical composition comprising an effective amount of a protein of claim 2 in admixture with a pharmaceutically acceptable vehicle.
23. A pharmaceutical composition comprising an effective amount of a protein of claim 3 in admixture with a pharmaceutically acceptable vehicle.
24. A composition of claim 20 further comprising a pharmaceutically acceptable matrix.
25. A composition of claim 21 further comprising a pharmaceutically acceptable matrix.
26. A composition of claim 22 further comprising a pharmaceutically acceptable matrix.
27. A composition of claim 23 further comprising a pharmaceutically acceptable matrix.
28. The composition of claim 20 wherein said matrix comprises a material selected from the group consisting of hydroxyapatite, collagen, polylactic acid and tricalcium phosphate.
29. The composition of claim 21 wherein said matrix comprises a material selected from the group consisting of hydroxyapatite, collagen, polylactic acid and tricalcium phosphate.



30. The composition of claim 22 wherein said matrix comprises a material selected from the group consisting of hydroxyapatite, collagen, polylactic acid and tricalcium phosphate.
31. The composition of claim 23 wherein said matrix comprises a material selected from the group consisting of hydroxyapatite, collagen, polylactic acid and tricalcium phosphate.
32. Use of the composition of claim 20 for the treatment of a patient in need of cartilage and/or bone formation.
33. Use of the composition of claim 21 for the treatment of a patient in need of cartilage and/or bone formation.
34. Use of the composition of claim 22 for the treatment of a patient in need of cartilage and/or bone formation.
35. Use of the composition of claim 23 for the treatment of a patient in need of cartilage and/or bone formation.
36. A pharmaceutical composition for wound healing and tissue repair said composition comprising an effective amount of a BMP-5, BMP-6 or BMP-7 protein in a pharmaceutically acceptable vehicle.
37. A pharmaceutical composition for wound healing and tissue repair said composition comprising

an effective amount of the protein of claim 1  
in a pharmaceutically acceptable vehicle.

38. A pharmaceutical composition for wound healing  
and tissue repair said composition comprising  
an effective amount of the protein of claim 2  
in a pharmaceutically acceptable vehicle.
39. A pharmaceutical composition for wound healing  
and tissue repair said composition comprising  
an effective amount of the protein of claim 3  
in a pharmaceutically acceptable vehicle.

# INTERNATIONAL SEARCH REPORT

International Application No PCT/US 90/01630

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup> According to International Patent Classification (IPC) or to both National Classification and IPC IPC5: C 12 P 21/00, A 61 K 37/36, C 07 K 13/00		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
IPC5	C 12 P; A 61 K; C 07 K	
Documentation Searched other than Minimum Documentation to the extent that such documents are included in Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>		
Category <sup>10</sup>	Citation of Document <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
A	Proc.Natl.Acad.Sci., Vol. 85, No. 24, 1988, Wang, Elisabeth A et al: "Purification and characterization of other distinct bone-inducing factors ", see page 9484 - page 9488	1-39
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A	WO, A1, 8910409 (GENETICS INSTITUTE, INC.) 2 November 1989, see the whole document	1-39
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A	US, A, 4789732 (MARSHALL R. URIST) 6 December 1988, see the whole document	1-39
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<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p><sup>10</sup> Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&amp;" document member of the same patent family</p> </div> </div>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
20th June 1990	17. 07. 90	
International Searching Authority	Signature of Authorized Officer	
EUROPEAN PATENT OFFICE	F.W. HECK	

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	WO, A1, 8800205 (GENETICS INSTITUTE, INC.) 14 January 1988, see the whole document  --	1-39
A	EP, A2, 0212474 (UNIVERSITY OF CALIFORNIA) 4 March 1987, see the whole document  --  -----	1-39

ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO. PCT/US 90/01630

SA 35737

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.  
The members are as contained in the European Patent Office EDP file on 24/05/90  
The European Patent office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO-A1- 8910409	02/11/89	AU-D- 3448789	24/11/89
US-A- 4789732	06/12/88	US-A- 4294753	13/10/81
		US-A- 4761471	02/08/88
		US-A- 4455256	19/06/84
		US-A- 4619989	28/10/86
		US-A- 4795804	03/01/89
WO-A1- 8800205	14/01/88	AU-D- 7783587	29/01/88
		EP-A- 0313578	03/05/89
		US-A- 4877864	31/10/89
EP-A2- 0212474	04/03/87	JP-A- 62111933	22/05/87
		US-A- 4795804	03/01/89

For more details about this annex: see Official Journal of the European patent Office, No. 12/82